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ATMOSPHERIC REFRACTION AT COLLEGE, ALASKA, DURING THE WINTER, 1947-1948

Pierre St. Amand and Harold Cronin

Abstract--Observations of atmospheric refraction of light from the Sun were made each clear day during the winter of 1947-1948. The method is described, tables and graphs are given to illustrate the results. A peculiar cyclical variation of refraction with altitude is noted. A table is appended suggesting possible corrections to mean refraction tables for use at this location. The need for further study is indicated.

Introduction--The frequent occurrence of mirages, (see Fig. 1 and 2) as seen from the campus of the University of Alaska at College, Alaska, combined with the presence of strong temperature inversions suggested that abnormal atmospheric refraction might exist at the lower celestial altitudes. It was decided to investigate this phenomenon in a preliminary fashion to determine if sufficient departure from published tables existed to warrant a more elaborate study. This paper details the results of the preliminary investigation which was carried out.

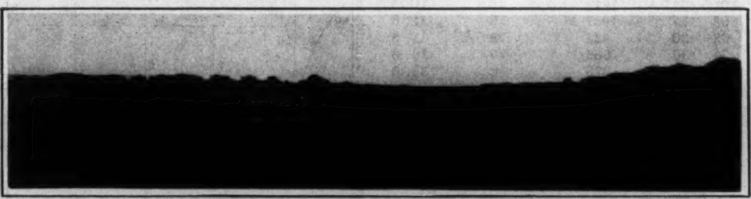

Fig. 1--Superior mirage, College, Alaska

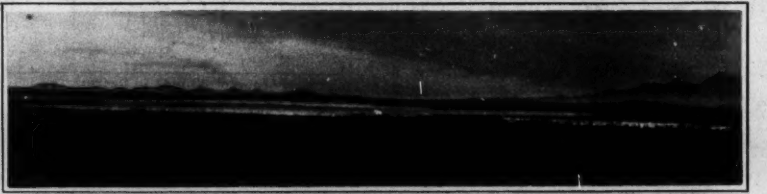

Fig. 2--Same view without mirage photographed under poor light conditions in March, 1950

Investigation--Because of the preliminary nature of the investigation, the observations were confined to measurements of solar altitude each noon in clear weather.

The instrument used, an eight-inch Berger theodolite, was disassembled, cleaned of all lubricant, reassembled, and completely adjusted. It was then mounted on a concrete pier. Adhesive tape was placed on all the tangent screws to prevent freezing of the operator's fingers in sub-zero weather. Coordinates of the pier were determined from those of a United States Coast and Geodetic Survey triangulation station as follows: 64° 51′ 22.″40 ± 00.″01 N; 147° 49′ 12.″80 ± 00.″01 W. These were subsequently checked by astronomical means.

The observational program was begun October 1, 1947, and ended March 8, 1948. A set of observations consisted of four pointings upon each limb of the Sun. Half were made before local apparent noon and half after. The first half were made with the telescope erect, the second with the telescope inverted. The instrument was leveled at the beginning of each set, checked in the middle and at end. The time of each pointing was read to the nearest 0.1 second. The chronometer was compared with radio time signals at the end of each set and the time of observation adjusted for chronometer rate. The temperature was read from a mercury-thallium thermometer upon entering the observation hut. Atmospheric pressure was read from a mercurial barometer and corrected for room temperature.

Reduction--The observations were each reduced to the meridian by the method outlined by DOOLITTLE [1885]. The mean meridian altitude of each limb of the Sun was computed. The true altitude of the respective limbs was then computed by the usual methods from data in the Nautical Almanac. The computed altitude was subtracted from the observed altitude for each limb to obtain the observed refraction. Expected refraction was then computed, with corrections for temperature and pressure, from the mean refraction tables given by Doolittle and subtracted from the observed refraction. Resulting refractions and departures from the tables were then tabulated along with the mean observed altitude, temperature, and pressure.

The data were then arranged in class intervals of one degree. The mean altitude of observation, mean observed refraction, mean deviations from the tables, and the standard deviation were computed for each class interval.

Table 1--Observed data grouped in class intervals of one degree

Observed altitude	Observed refraction	Mean deviation	Standard deviation
01° 52′	1212″	42″	10.″5
02 57	1087	55	31.6
03 30	923	78	41.6
04 30	685	15	36.0
05 32	578	18	32.6
06 29	516	06	08.3
07 21	454	02	22.6
08 34	421	26	16.6
09 34	339	-12	13.5
10 32	318	00	14.9
11 26	307	02	04.8
12 29	275	-03	09.8
13 28	249	-03	28.0
14 30	235	07	12.5
15 27	215	01	08.4
16 45	207	07	07.3
17 32	191	08	09.2
18 31	202	16	07.0
19 29	186	10	20.8
20 27	155	00	13.6

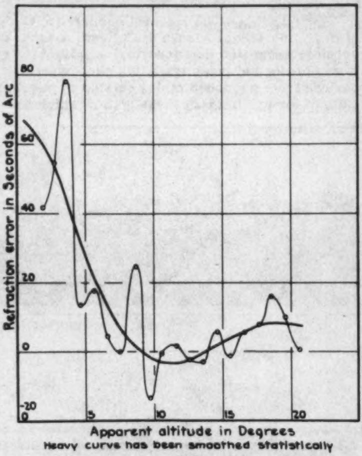

Fig. 3--Observed deviations from published refraction tables as a function of altitude; heavy curve smoothed statistically

Results--Results appear in Table 1. Figure 3 shows a graph of the deviations from the expected refraction plotted against altitude. Figure 4 shows the standard deviations plotted against altitude. The thin line in both figures is for one-degree intervals, the heavy lines representing a smoothed function. Figure 3 may be used to estimate the reliability of observations made in this locality at low altitudes with the method described and to estimate the variations in refraction from day to day.

Discussion--The most noticeable thing about the unsmoothed curve in Figure 2 is the presence at certain altitudes of large departures from the tables. There appears to be a cyclical function with a period of about two degrees added to the simpler function represented by the smoothed curve. The reality of this peculiar variation is of course open to question and the matter can not be resolved without making additional observations. It is possible that this variation is due to the presence of several well-defined temperature inversions which overlie the valley on winter days.

It is thought that a light ray might enter an inversion layer at a certain angle and be bent more at that angle than at any angle above or below it. Such a phenomenon might account for the observed fluctuations especially since there is more than one inversion in general. It is significant, perhaps,

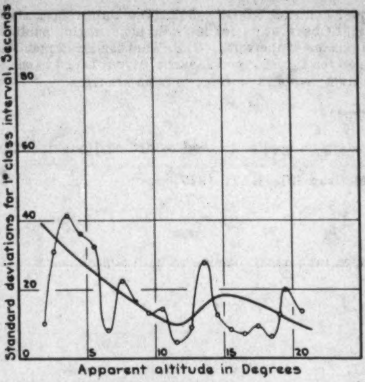

Fig. 4--Standard deviation of observed departures from tables as a function of observed altitude; illustrating the scatter to be expected at different altitudes when making low altitude observations; errors of observation have not been removed

that the scatter in the observed refraction is greatest at the altitudes at which the mean deviations are greatest. This would result if an inversion whose height varied slightly from one day to the next were involved.

Some inversion data were obtained from the United States Weather Bureau at Fairbanks, and an attempt was made to find a correlation with the observed deviations, but no simple relation could be uncovered.

According to the simple theory of atmospheric refraction, the only factors influencing the total deflection given a ray of incoming light are the velocities of the ray in the first and final media, respectively, and the initial angle of incidence [HUMPHREYS, 1929]. Since the effects of water vapor are usually minute, especially at this station, there should always be the same amount of refraction under the same conditions of temperature, pressure, and altitude. The reason for this is evident. We can measure conditions of temperature and pressure with accuracy, and define, in effect, the index of refraction in the final media. The index in the first media may be assumed to be unity. So it would seem that the observed irregularities could not take place. However, if the angles involved at the surfaces of the inversion layers may be considered, the changes could perhaps be attributed to them. These considerations indicate that a theoretical investigation of the problem should prove fruitful.

Conclusions--It is concluded that, in an emergency, the low lying Sun could be used for navigational purposes provided that the navigator was aware of the possibliity of an error of as much as two miles in latitude and corresponding errors in longitude and time. It is impossible to carry out geodetic work under these conditions.

If refraction tables for navigational work were corrected to compensate for the major departure, the probable error as deduced from the standard deviation would be about 30 sec. This preliminary work leads one to believe that the corrections in Table 2 would be about the order of magnitude which should be applied to the existing tables.

Table 2--Suggested corrections to tables of refraction

Apparent altitude	Correction to refraction
1°	80″
2	69
3	53
4	40
5	30
6	22
7	14
8	07
9	02
10	-01
11	-04
12	-04
13	-02
14	01
15	03

Ordinarily no one would attempt to observe at these altitudes, but because of the long twilight in the arctic when the stars can not be seen, it becomes necessary for aircraft to use the Sun whenever they can to determine position.

Recommendations--The observational program should be repeated in modified form in coming winters to determine the reality of the departures found in this preliminary work and to define them with greater accuracy. It would seem advisable to use the stars rather than the Sun. This would result in simplified computation and greater accuracy. In addition, it would be desirable to measure the refraction at a number of different altitudes under the same conditions of temperature and pressure so that a more detailed study could be undertaken.

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VISIBILITY OF SIGNAL CLOTH UNDER TROPICAL CONDITIONS

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Abstract--Experiments were performed on the visibility of signal cloth used in the tropics for hydrographic and geodetic signals. The cloth tested included the normal muslin and bunting in use by the Hydrographic Office and five brilliant fluorescent cloths. Visibility was checked in a relative sense by two impartial naval observers using fresh and faded cloth under various tropical weather conditions. A scale of relative visibility was devised and the data plotted on histograms for ease of comparison.

All fluorescent cloths were found to have a high visibility index under sunlight owing to various colors of the cloths. Ordinary bunting and muslin signal cloth, though of lower visibility under most weather conditions, faded less than fluorescent cloth. Estimates of loss in brilliance by fading are given in tabular form. It is concluded that reduction in signal size is possible, with attendent savings in the smaller construction, if fluorescent cloth is utilized on geodetic projects which can be completed before serious fading obviates its visual advantages.

The problem

Hydrographers memorandum--The availibility of fluorescent signal cloth in quantity early in 1944 caused the Hydrographer of the U. S. Navy to issue memoranda to various naval field parties requesting experiments on the relative visibility of the new fluorescent signal cloth and ordinary muslin signal cloth. Fluorescent signal cloth was transmitted to the author in the Pacific Ocean area in May, 1944, with the request that tests be run under normal operating conditions to determine the advisability of changing large geodetic and hydrographic signals to smaller signals at a lesser cost.

Purpose of the Experiment--Visibility experiments were made to determine the color and type of cloth best suited to geodetic and hydrographic surveying under tropical conditions. Specific recommendations were requested concerning the possibility of cutting down the sizes of signals owing to their inherent danger to observers working with large signals near enemy territory and because of the greater cost of constructing large signals.

The site of observations, type of cloth mount, and list of cloth types tested are shown in Figures 1, 2, and 3. Station J was located on a low coral islet without palm tree cover where bottom reflected light from coralline sand is of high intensity. Station H was located on a palm covered island with dense undergrowth.

Procedure

Equipment and technique--Nine strips of cloth were cut 2.68 inches wide, representing a four-second intercept at 1.892 nautical miles. Nine other strips were cut 5.36 inches wide, representing an eight-second intercept at the same distance. Each cloth type was thus represented by two intercepts, the one barely visible, the other quite easily seen. In addition, nine flags 5 1/2 inches by 11 inches were cut in triangular pattern, representing one flag for each cloth type (see Fig. 2).

Each observer pointed from left to right on the four-second and eight-second intercept strips mounted on the frame, and called out the descriptive visibility to the other observer. No other conversation was permitted between observers during the entire set of pointings.

Visibility indices--The observers established a relative scale of visibility based on photoelectric cell readings on white cloth reflecting varying amounts of light. Both observers practiced calling off numbers and descriptive terms representative of the relative scale so established, before the cloth strips were observed.

The following is the scale used: (1) invisible; (2) barely visible; (3) slightly visible; (4) moderately visible; (5) highly visible; (6) faintly bright; (7) moderately bright; (8) bright; (9) very bright; and (10) dazzling.

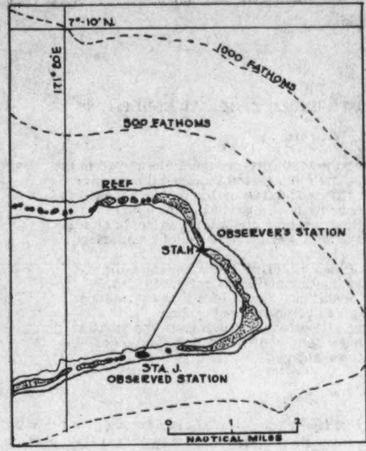
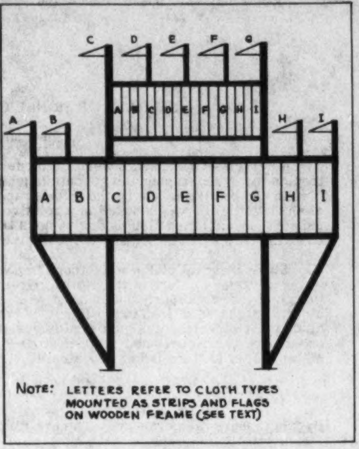


Fig. 1--Site of observations, Majuro Atoll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NOTE: LETTERS REFER TO CLOTH TYPES MOUNTED AS STRIPS AND FLAGS ON WOODEN FRAME (SEE TEXT)

Fig. 2--Cloth mount frame (schematic)

The arbitrary nature of the vocabulary used in this numerical sequence is recognized, but the addition of words to qualify a number applied to relative visibility was indispensable because of the necessity of gaining quantitative data from a qualitative experiment.

Observations

The results of the observations are shown in Figure 3. Observation X was made with the signal in bright sunlight; ten per cent cumulus clouds in the sky; temperature 80°F; few radiation waves; and light winds from NNE which caused no flutter of the strips or flags. The sun was high in the sky to the east of the cloth strips. Observation X was made at 10^h30^m on January 5, 1945, immediately after the mount was constructed.

Observation Y was made on a very dark gray day with complete overcast, over and behind the observers' station. Variable light was notable over the observed station but no radiation waves were visible; light northeast trade winds which caused no appreciable flutter of strips or flags; temperature approximately 75°F. Observation Y was made at 14^h30^m on January 30, 1945.

Observation Z was made under a brilliant sun with few scattered cumulus clouds behind the observers' station; signal and observer in bright sunlight; sun high and behind the signal cloth mount; many radiation waves; moderate northeast winds which caused slight flutter of the strips and flags. Observation Z was made at 14^h30^m on January 31, 1945.

Cloth fade--Fifteen days of exposure to salty water spray, brilliant sunlight, and constant wind caused notable changes in the color and hue of the fluorescent cloth, whereas the muslin and bunting changed only slightly. Observations Y and Z were made on these faded cloth strips. Estimates made in the laboratory of change in visibility and change in color are listed in Table 1. It must be noted that these laboratory estimates of total hue change do not correlate well with field estimates of total visibility change. This exphasizes the relative nature of the experiment, and suggests that hue is only one important factor in visibility.

Conclusions

Since the distribution of data does not embrace all weather conditions during various seasons of the year, visibility variations were injected by varying sunlight, extreme fade in the fluorescent

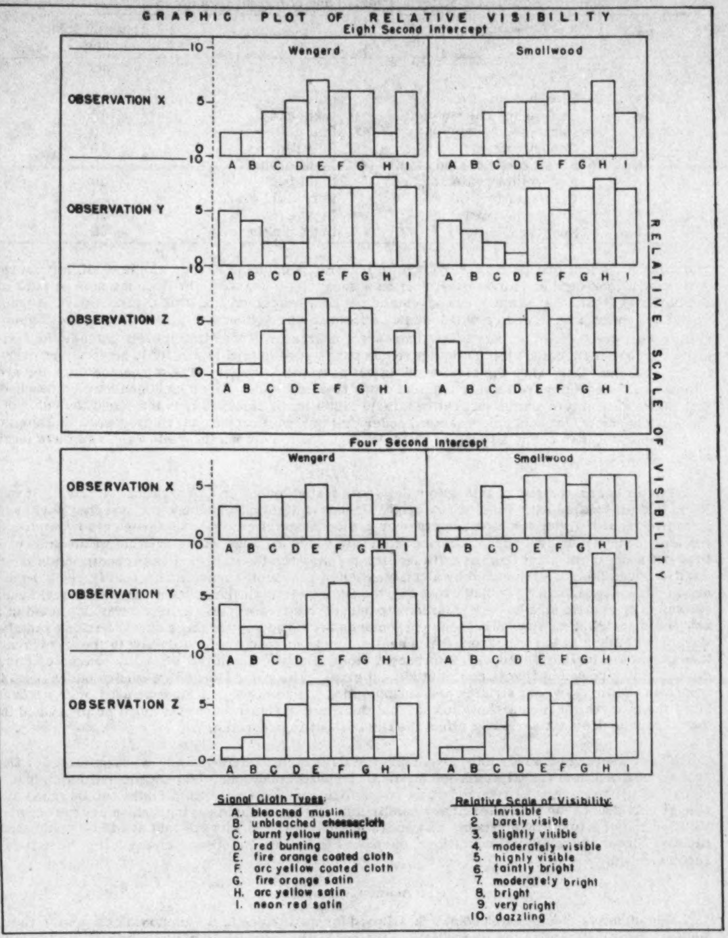

Fig. 3--Plot of relative visibility

cloths, and differences existed between estimates of two observers. Observational differences between two observers were sometimes found to be as great as actual visibility differences between cloth types.

Comparisons among all observations prove what most field men know about the comparative

Table 1--Materials tested and color changes noted

Item	Type of cloth	Fade color	Apparent loss in hue
			pct
A	Bleached muslin	No change	5
B	Unbleached cheese cloth	Light gray	10
C	Burnt-yellow bunting	Dull yellow	5
D	Red bunting	Dull red	10
E	Fire-orange coated cloth	Light orange	20
F	Arc-yellow coated cloth	Light buff	30
G	Fire-orange satin	Very light orange	30
H	Arc-yellow satin	Light gray	50
I	Neon-red satin	Light pinkish gray	60

visibility of colors; that is, that the yellow-orange range contains shades which, if slightly more yellow, will look light and almost invisible on a sunny day when the light is on the side or back of the cloth; whereas, that same shade will stand out as a beacon on a dull or overcast day. A color containing more orange will be dull to dark on an overcast day but will gleam on a sunny day no matter what the angle of the sun. The fluorescent character of the cloth merely extends the visibility range of all treated cloth so that a remarkable agreement of visibility is noted under overcast conditions. Only when the cloth width is cut down to a barely visible dimension does the arc-yellow satin show up more readily than the other treated cloths. The conclusion may be reached that fluorescent impregnation or coating affects visibility of cloth far less than does the color of the cloth under bright sunlight; whereas, under dull overcast conditions, fluorescence of cloth is more important than color, as long as the color is a shade between the yellow and red wave lengths of the spectrum.

Flutter characteristic of triangular flags was tested briefly in Observations X and Y. It was found that all treated satin flags threw bright flashes of light under sunny and overcast days, with fire-orange satin giving the best results over a wide range of conditions. Coated cloth was found too stiff to flutter in light winds, During moderate winds all flags were invisible while hanging limp but showed pin-point flashes sufficient for pointing the theodolite. Phase conditions in the Pacific Ocean Islands are caused by a combination of radiation waves and constantly changing angles of sun-strike on signals. Flashes caused by the flutter of small fluorescent flags were vivid and showed very erratic side-to-side positions in successive flashes; this anomaly was not noted in the non-fluttering cloth strips. Since this phenomenon occurred only on flags during serious radiation waves, the author is led to suggest that a negligible phase condition would exist in the tropics on triangulation signals covered with fluorescent cloth. Despite the initial visibility characteristics, the sustaining power of fluorescent cloth is not great. The color fade which occurs under normal tropical conditions is both striking and disappointing where the signal must be used over ten days. Since the observational data show no apparent decrease in fluorescence, it might be presumed that the color fade does not seriously affect the fluorescent impregnation.

The fire-orange coated cloth, unsuitable for flags, and the fire-orange satin, suitable for flags, appear most suitable for triangulation under all tropical conditions. The author estimates that signals of all types may be reduced about one-half in size. If fluorescent cloths can be made available at only double the cost of ordinary muslin and bunting, notable savings which accrue from smaller construction would become an important cost factor in surveys that are to be completed rapidly. Under these special conditions, the use of fluorescent cloth for triangulation signals is recommended.

Acknowledgments

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VELOCITY OF LONGITUDINAL WAVES IN SOME PALEOZOIC FORMATIONS IN THE VICINITY OF ST. LOUIS, MISSOURI

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Abstract--The velocity of propagation of longitudinal elastic waves in five Paleozoic formations that crop out in the vicinity of St. Louis, Missouri, was determined by means of a series of short range seismic profiles. The instrumentation is described. The possibility that the magnesium carbonate content of a carbonate rock is a dominant factor controlling the velocity of elastic waves through it, is suggested.

Introduction--During the first three months of 1949, field data were collected for the determination of the velocity of elastic waves through a number of Paleozoic sediments in the region around St. Louis, Missouri.

It was hoped originally that it would be possible to distinguish the beginning of the shear wave group on the records, but this proved impossible. Although shear waves apparently are present on some of the records, their beginnings are lost in the longitudinal waves. Therefore, it was decided that study of shear waves was impossible with the method used, and attention was devoted entirely to longitudinal waves.

Procedure--The technique employed was first to locate fairly extensive exposures of the formation to be studied, and then to record, by means of seismographs, the arrival, at various points on the surface of the formation, of the waves generated by a dynamite explosion.

The theory of seismic wave propagation shows that, if the seismometer stations are close to the shot point compared with the thickness of the formation, and on the same horizontal plane, the path of the first wave to each geophone is approximately the straight line from the shot point to the seismometer. Therefore, the travel-time curve for the first arrivals will be a straight line through the origin with a slope which is the reciprocal of the velocity in the medium.

Quarry floors are excellent profile sites in that they furnish extensive, fresh exposures of the formation. In a region of generally slight dips, as in this area, the floors of the quarries are practically horizontal. The author is indebted to the quarry operators of the area who generously cooperated in this study.

An explosion of two and one-half to four pounds of 40 per cent gelatine dynamite was used in all but one case. In the other case 60 per cent dynamite was used. The charges were placed directly on the rock surface, or in shallow holes, and tamped with mud or sand. Each stick was capped, in order to make the shot as instantaneous as possible, and also as a safety measure.

Instrumentation--Two types of circuits were employed to transmit the shot instant. One, used at two of the profile locations, consisted of a dry-cell circuit through the input to one of the galvanometers and a wire wrapped around one of the dynamite sticks. The breaking of the wire by the blast caused the galvanometer to be deflected. The second type of circuit used a radio transmitter-receiver arrangement, in which the output of the receiver was fed to one of the galvanometers. The interruption of the steady carrier from the transmitter by the blast produced a pulse on the record. The pulse from the radio circuit was found to lag the direct pulse by approximately 0.0005 sec.

The seismometers consisted of a cylindrical coil of 1600 turns of 39 gage wire, suspended by means of spring-tempered bronze diaphragms in the circular air gap of an Alnico magnet. The magnet was made up of a hollow cylinder fitting snuggly into the geophone case, within which was fitted concentrically a spool-shaped piece, which flared out to contact the outer part at the bottom. There was a three-sixteenth inch air gap at the top.

The coil was approximately three inches in diameter, one-sixteenth inch thick, and an inch high. Copper foil wrapped inside and outside the coil supplied the damping. These parts are shown in Figure 1, with the coil itself concealed by the outer damping foil.

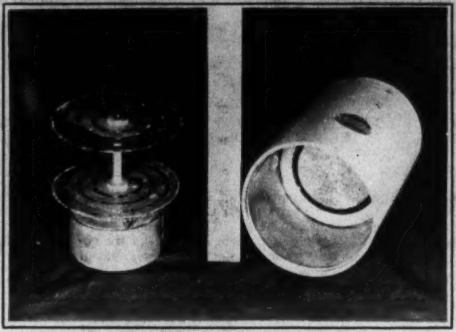
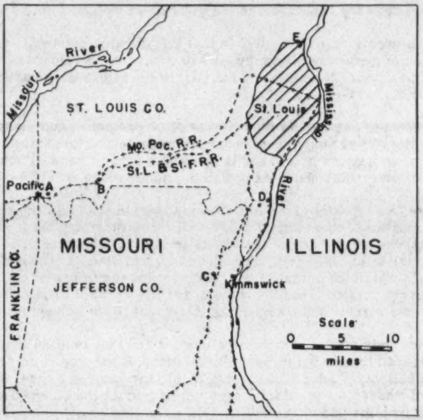


Fig. 1--The dissembled geophone, with the coil, concealed by the damping sheath, and the bronze diaphragms (left), and the Alnico magnet, showing the air gap, in the bottom of the geophone case (right)

The resonant frequency of the geophones was approximately ten cycles per second. Thus, they were designed to be especially sensitive to waves with the frequencies to be expected in the region around the blast.

The records were made with a conventional prospecting type camera; but the six special galvanometers in the bank had a natural period of about 0.1 sec, in resonance with the seismometers. No amplifiers were used, as the seismometers were coupled to the galvanometers by means of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ILLINOIS
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JEFFERSON CO.
C
Kimmswick
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Fig. 2--Map of profile locations; A, St. Peter sandstone; B, Joachim dolomite; C, Kimmswick limestone; D. St. Louis limestone; E, Cherokee formation

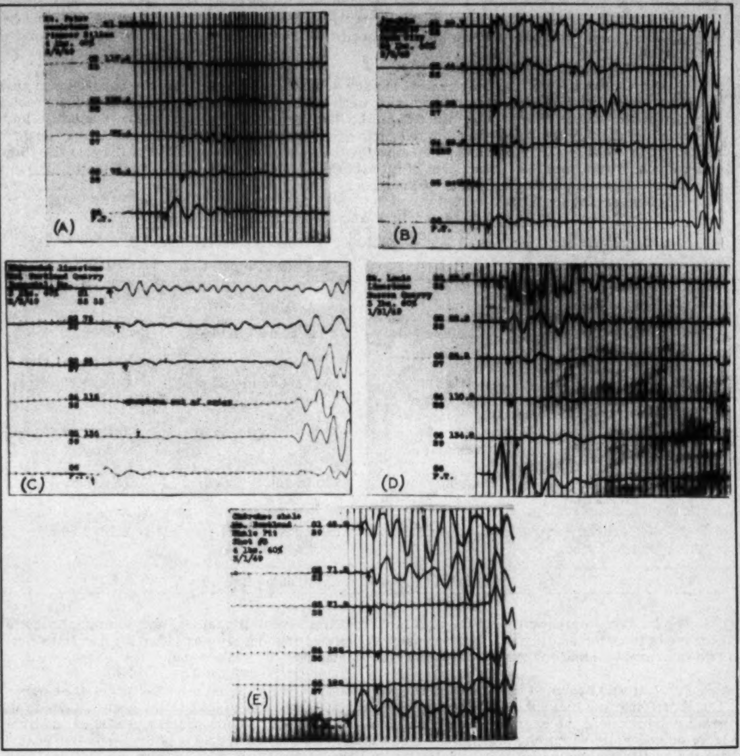

Fig. 3--Examples of records obtained; (A) St. Peter sandstone; (B) Joachim dolomite; (C) Kimmswock limestone; (D) St. Louis limestone; (E) Cherokee formation

matching transformers. The overall dynamic magnification of the recording channels at resonance, as determined by shaking table tests, was about 1000.

Time marks, produced by a tuning-fork-controlled oscillator, were put on the records every 0.01 sec.

The profiles--Five formations were selected for the study from the many Paleozoic sediments cropping out in the region. These were chosen as representative of the consolidated sediments of the area, and because good exposures were available for seismic work. The map in Figure 2 shows the location of the profile sites.

One record obtained for each formation is shown in Figure 3. The firing-time pulse is indicated on the bottom trace of each record, and the first arrival on each trace is marked with an arrow. On Figure 3B, for the Joachim dolomite, the second phase marked is the result of the air wave from the blast striking each geophone. The large deflections at the end of this record, and also present at the ends of some of the other records, is due to the air wave hitting the recording truck. This deflection, of course, is present on all traces, even those to which no geophone was connected.

The number prefixed by G at the beginning of each trace is the galvanometer number, that by S, the seismometer number, and the third number is the distance in meters from the shot-point to the station.

Results--The time of the first arrival at each geophone was read from the records with an excellent micrometer microscope, with accuracy well within the limits of error of the other procedures. The travel-time function was determined from the data by means of a least squares solution, and the theory of small samples was utilized to determine the confidence limits of the velocities found from this function. The range of values given below for the velocities in each case is that range within which the probability is that 80 per cent of all samples of the velocity taken within the formation will fall. Table 1 summarizes the results of the study.

Table 1--The velocity of longitudinal waves in some paleozoic formations in the vicinity of St. Louis, Missouri

Formation	Age	Portion of formation	Velocity
			km/sec
St. Peter sandstone	Middle Ordovician	60 ft below the top	2.85-2.90
Joachim dolomite	Middle Ordovician	65 ft above the base	6.06-6.80
Kimmswick limestone	Middle Ordovician	30 ft above the base	1.73-2.06 (?)
St. Louis limestone	Mississippian	125 to 150 ft above the base	3.62-3.86
Cherokee formation	Pennsylvanian	Blue shale, 60 ft above the base	2.16-2.28
		Cheltenham fire clay	2.9 (?)

The correct interpretation of the data from the Kimmswick limestone, was somewhat doubtful because of the wide scattering. Five records were made in a quarry near Kimmswick, Missouri. Two interpretations of the travel-time data from these records were made.

First, it was assumed that the data did represent scattering about a single travel-time curve. The scattering was blamed on errors in picking out the true first breaks in the records, due to the great dissipation of the energy in this rock, or possibly in part on horizontal and vertical departures from homogeneity within the formation. It is possible that the entire 30 ft of the formation underlying the profile is a weathered low-velocity layer, although the floor of the quarry was cut in recent years and seems to be fresh. If this were a weathered zone, that fact alone could explain the difficulties.

The first interpretation yielded a velocity of 1730 to 2055 m/sec for the horizon 30 ft above the base of the formation. A second interpretation was based on the assumption that some of the first arrivals has penetrated through the Kimmswick, and had traveled below it as a refracted wave. This interpretation yielded a velocity of 1790 m/sec in a layer 30 ft thick, overlying a layer in which the velocity is 3010 m/sec. This result seems to fit the data closely, especially since the thickness of the Kimmswick determined agrees so well with the known geology.

If this interpretation is correct, it means that the profile straddled that portion of the formation in which direct and refracted waves arrived intermingled. There is insufficient information to justify a choice between the two interpretations.

For the Cherokee formation, a velocity of 2160 to 2275 m/sec was determined for a blue shale 60 ft above the base of the formation. There were only six feet of this blue shale under the profile spread, with fifty feet of Cheltenham fire clay below. A refracted wave arrived first at the farthest stations, and yielded a preliminary value for the velocity in the fire clay of 2900 m/sec.

The velocities found here for carbonate rocks, together with the fact that the bulk and shear moduli of magnesium carbonate are greater than those of calcium carbonate, point to the possibility that the magnesium carbonate content may be an important factor in determining the longitudinal wave velocity. The following percentages of these two compounds in the three carbonate rocks studied here are given by HINCHEY, FISCHER, and CALHOUN [1947].

Joachim dolomite: calcium carbonate, 55 per cent; magnesium carbonate, 36 per cent
Kimmswick limestone: calcium carbonate, 97.8 to 99.4 per cent; magnesium carbonate, a trace
St. Louis limestone: calcium carbonate, 75.3 to 82.6 per cent, magnesium carbonate, 7.7 to 10.0 per cent

The samples from which these percentages were determined were taken from the same quarry sites where the profiles were made. In each case, the increase in velocity is accompanied by a corresponding increase in percentage of magnesium carbonate content. This correspondence was originally noted in attempting to explain the departure of the Kimmswick from the general rule that velocity increases with age of deposition. Further study is requried before the relative importance of age of deposition and chemical composition in the determination of velocity can be judged. This is especially true in view of the doubt with regard to the velocity in the Kimmswick.

It is suggested that it is replacement of part of the original calcium carbonate by magnesium carbonate deposition, rather than an increase in the degree of lithification alone, that accounts for the general increase of velocity with age. Those exceptions to this generalization may be explained as due to lack of conditions favorable for such a replacement during the geologic history of the rock.

In conclusion, it might be said that while the data used for the determinations were somewhat sparse, the primary intent was to gain an overall picture of the velocity characteristics of the sediments in the region, and to point out any features that might be of interest for further study.

Acknowledgments--The author is indebted to Florence Robertson and the other members of the staff of the Institute of Technology of St. Louis University who gave valuable advice and assistance in the completion of this study. Also, gratitude is expressed to the Shell Fellowship Committee, whose financial assistance made this work possible.

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THE GLACIAL ANTICYCLONE THEORY EXAMINED IN THE LIGHT OF RECENT METEOROLOGICAL DATA FROM GREENLAND--Part 2

François E. Matthes and Arthur D. Belmont

(Prepared by the junior author from notes of the senior author after his death.)
[For Part 1, see Trans. v. 27, pp. 324-341, 1946]

Abstract--The frequent bad weather on the Greenland Ice Sheet is caused by cyclones which although they may be deflected along the coasts, can and do cross Greenland. Eismitte surface records are presented as evidence of an actual crossing. Cyclones along the east coast are as important as those on the west coast as a source of the ice sheet's alimentation. Further supporting evidence on the storminess of the Greenland interior is given by the records of three other expeditions. Despite the use of only a few summers of records, conclusions may be considered reliable since the records of several different expedition years are all in agreement with respect to the lack of fair weather.

The existence of three distinct major domes on the ice sheet precludes, in itself, the single fixed anticyclone which Hobbs postulates. Radially outflowing winds do not in themselves signify the presence of an anticyclone. Hobbs' persistent confusion of the downslope, gravity-caused flowing of cooled surface air with the general outward radiating winds of a high pressure center, the only anticyclone defined in meteorology, has been the basic misconception of his belabored theory. The "anticyclone" as defined by Hobbs was pointed out by Mills in 1926 as being entirely different from the meteorologists' concept of a high pressure area, and it seems time that the continued confusion of ideas be replaced by clear thinking.

Foreword--The late Dr. Matthes left notes for the continuation of Part 1 of his paper on the Greenland anticyclone [MATTHES, 1946]. As stated in the abstract of Part 1, he intended to present in Part 2 aerological data from Eismitte and data from other stations on the Ice Sheet. Unfortunately, his notes were not completed, and although he was in the process of investigating several other data sources and recent papers, his drafts contain mainly additional surface evidence from Eismitte and from three other expeditions which are given here. From brief written comments and excerpts from several references, it is evident he planned to discuss the papers by DORSEY [1945], HOBBS [1945], FLINT [1946], SVERDRUP [1935], and BROOKS [1923].

Since the time that Dr. Matthes worked on this subject the following papers have appeared, among others, which he certainly would have included and which are listed here as further references for the interested reader: DZERDEEVSKI [1945], HOVMØLLER [1947], HOBBS [1948], and GEORGI [1948].

Since there is much additional material that might be included in the current discussion, it was felt best to combine here only the existing notes into as much continuity as possible in order that the paper remain essentially as written by the senior author. The junior author has taken the liberties of eliminating much of the duplication found in the notes and of amending slightly certain statements of meteorological theory. The junior author concurs with the evidence and arguments presented and is willing to enter into any discussion of them.--A. D. B.

Additional evidence from the Wegener Expedition--What may be the explanation of all the storminess in central Greenland, which Hobbs evidently did not suspect when he first framed his hypothesis and which he now apparently ignores in spite of indubitable evidence? The complete answer is not furnished by the Eismitte (see Fig. 1) records alone, nor were the meteorologists of the Wegener Expedition at all sure of their interpretations. They notably wavered and even changed their minds while writing their final reports. But several important facts nevertheless stand out unmistakably from the Eismitte records; these deserve to be pointed out.

It could not be doubted that the snow was brought to Eismitte by cyclones that had glided up on the Ice Sheet, over the thin layer of outflowing cooled air, for with the oncoming of each storm, Georgi observed the cloud formations characteristic of the front of a depression. As the cloud

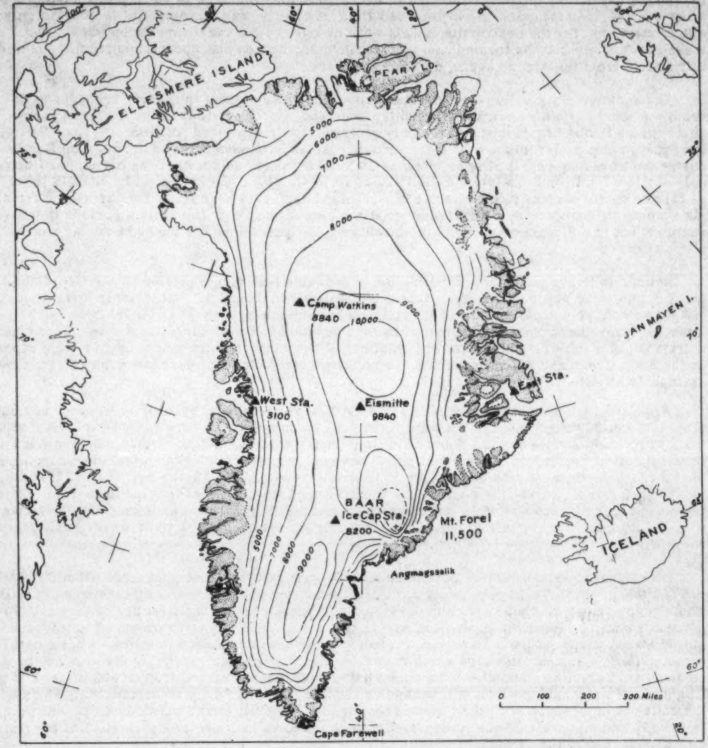
ELLESMERE ISLAND
PEARY LD.
5000
6000
7000
8000
9000
10,000
Camp Watkins
8840
West Sta.
3100
Eismitte
9840
East Sta.
JAN MAYEN I.
BAAR
Ice Cap Sta.
8200
Mt. Forel
11,500
Angmagssalik
ICELAND
Cape Farewell
0
100
200
300 Miles
75°
70°
60°
20°

Fig. 1--Map of Greenland showing approximate contour in feet

cover expanded and radiation from the Ice Sheet became more and more obstructed, the temperature rose, the barometer fell and the surface winds, which normally blew from the east, or the east-southeast, were replaced by violent storm winds from the south or the south-southwest, bringing low clouds and snow.

As to whether these cyclones merely spread laterally over Greenland as their centers traveled up along either the west coast or east coast, and as to whether some of them actually passed across Greenland from west to east, are questions on which opinions differ. Of prime importance, it seems to the writer, is Georgi's conception of those atmospheric movements, for he is the only meteorologist and aerologist who closely and methodically observed the weather in central Greenland for an entire year. Although for some unknown reason he contributed no formal discussion of his observations to the reports of the Wegener Expedition, his convictions are well known, both from what he told his colleagues and from his paper [GEORGI, 1933].

Particularly clear are the indications contained in the records that cover the winter months. As already pointed out, those eight months at Eismitte were marked by a sharp alternation of violent snow storms with relatively high temperatures, and clear-weather periods with exceedingly low temperatures, the fluctuations from high to low often amounting to 20 to 30° C and sometimes to 40 or even 50°. Obstruction of outgoing radiation, of course, was an important factor, but only a secondary one, for the obstructing clouds were brought by the maritime air masses. That these invading air masses formed part of cyclonic disturbances that approached from the outside is manifest from the accompanying drops in pressure.

The summer storms, however, differed from the winter storms in several respects as is readily evident from the contrast between the June and March sections of the four-foot graph sheet (which Hobbs has reproduced but only superficially interpreted) [HOBBS, 1944, p. 94]. During typical summer storms the thermometer rose as a rule only five to ten degrees C but during the winter storms it rose as much as 20 to 50 degrees. In summer the barometer fluctuated only six to 13 mb, but in winter it often varied 26 to 40 mb. The statement by HOBBS [1944, p. 75] that during storms in the interior of Greenland explorers have found the barometer remaining "steady throughout" therefore holds good in a general way only for certain periods in midsummer, but is not representative of the conditions that prevail during the eight colder months of the year.

Neither is Hobbs justified in creating the impression that during storms on the Greenland Ice Sheet the wind never varies more than a few degrees in direction, that it never turns completely around the compass, and that it continues down slope throughout [HOBBS, 1944, p. 77]. True, explorers have observed such approximate constancy of wind direction during minor summer storms but they have also noted marked rotations of the wind. Nansen's account of a snow storm on the South Greenland Dome in which the wind turned suddenly from east to northwest is a classic example [NANSEN, 1890, v. 2, pp. 66-71].

From Georgi's graph sheet, Figure 3 of Part 1, it is clear that frequent occurrence and complete turns of 360 degrees were not rare, especially in summer, the only season explorers' observations were made and which data Hobbs uses as primary evidence for his theory, During August and the first half of September, 1930, three times the wind turned completely around the compass, from east through south, west, and north, back to east; and between May 14 and August 6, 1931 it made eleven such turns. During the eight winter months there were at least ten complete turns, not counting those cases marked doubtful. All these shifts can not be construed as Hobbs' light variable winds of the cold interior region because typical evidence of cyclonic activity were usually associated with them.

Hobbs characterizes central Greenland as a "region of calms and light airs" [HOBBS, 1926, p. 77; 1943, p. 383]. There was really not a single day that could properly be termed calm in the whole year. Only a few hours of calm prevailed on August 1, 1930, the first day of Georgi's sojourn at Eismitte. Winds of about 18 m/sec lasting for a whole day were observed in winter and other steady strong winds (at least 10 m/sec, excluding gusts) were recorded in every winter month. In summer (May - August), the wind speed rose from its average four m/sec, to eight m/sec or more on about six occasions, including a day and a half period when it varied from 10-13 m/sec. If by "light airs" we consider winds of less than two m/sec, the record shows actually only 12 days in the entire year on which such light winds prevailed for several hours, and of those 12 days, only two are in summer. Thus, Hobbs' description appears to be no more representative of the summer season than of the winter.

Kopp and Holzapfel, the meteorologists who had charge of the East and West Stations (see Fig. 1) respectively, of the Wegener expedition, find that on 45 different days the wind at Eismitte turned about 180 degrees from the usual east-southeast direction through southwest to west-northwest and on 30 days it turned about 90 degrees [KOPP and HOLZAPFEL, 1939, v. 4, Part 2, p. 319]. These authors conservatively estimate that complete round-the-compass rotations of the wind occurred ten times; but Georgi's graph sheet for winds actually shows 30 instances of clearing weather after storms, with winds shifting to the northwest, the north, or even to the north-northeast. The repeated occurrence of such shiftings of the wind immediately after storms, and only then, surely can not be explained each time as a mere coincidence.

These clearing winds, however, were usually rather light and not comparable to the strong gales that accompany cold fronts in our latitudes. For that reason the meteorologists of the Wegener Expedition were very cautious in their interpretations; but it is to be borne in mind that in Greenland, as soon as the sky clears, radiation from the ice sheet starts up again, the temperature drops sharply, and the gravity currents of cooled air resume their usual downslope courses, thereby obscuring for a ground observer the movements that take place in the free atmosphere above.

The consensus of the German meteorologists was that most of the cyclones reached Eismitte from the west coast, that some of them, however, come from the east coast, expanding across the divide of the ice sheet, and that occasionally cyclones came from both directions at once. The majority of the cyclones, moreover, appeared to withdraw again to the side from which they had come [KOPP and HOLZAPFEL, 1939, v. 4, Part 2, p. 312].

As regards the possibility of cyclones passing clear across Greenland, from west to east, Kopp and Holzapfel at first hesitated to commit themselves. Though convinced that neither the height of the Greenland massif, nor the shallow stratum of outflowing surface winds, nor both of these factors combined, constitute an insuperable obstacle for cyclones of great depth, they nevertheless thought at first that there was no clear evidence of the transit of a cyclone across Greenland during the observation year 1930-1931 [KOPP and HOLZAPFEL, 1939, v. 4, Part 2, p. 316]. Finally, having compared more closely the meteorological records of the three stations of the Wegener Expedition, and apparently having overcome their doubts and inhibitions, they produced what seems very satisfactory proof of the transit of a cyclone across Greenland. They point out that when a cyclone travels across Greenland from west to east, the low will be recorded first at the West Station, somewhat later at Eismitte, and still later at the East Station. Precisely such a case is indicated in the records of the three stations during the period March 23-25, 1931. Their statement follows [KOPP and HOLZAPFEL, 1939, v. 4, Part 2, p. 325]: "The low passed West Station on March 23, at 4 p.m.; it passed Eismitte on March 24, at 12 noon, and it reached East Station on March 25, at 4 a.m. A cyclone thus appears actually to have traveled across the inland ice. The center of the depression traversed the distance from West Station to Eismitte (245 mi) in 18 hours, and the greater distance from Eismitte to East Station (310 mi) in only 14 hours. Its speed therefore must have been accelerated during the descent from the ice cap, and retarded during the ascent."

The authors reproduced the barograms from the three stations for ready comparison and appended a table that showed among other things, the round-the-compass shifting of the wind at Eismitte. On March 23, at 08^h00^m the wind was still east-southeast (downslope); by 21^h00^m it had shifted to the south; it stayed south until 14^h00^m on March 24; then, about 21^h00^m it veered to the northwest. On March 25, at 08^h00^m the wind had turned east, and by 14^h00^m it was back in its usual east-southeast quarter.

Perhaps Hobbs has not discovered this evidence of the passage of cyclones across Greenland in the voluminous reports of the Wegener Expedition. The complete round-the-compass shifting of the wind at Eismitte just cited, it should be added, is duly indicated in the March section of Georgi's graph sheet which Hobbs has reproduced [HOBBS, 1944, p. 94]. It was accompanied by a drop of the barometer of 37 mb, followed by a rise of 29 mb. But this is by no means the only instance of a complete rotation of the wind accompanied by a barometric depression that is shown on the graph sheet. There are 29 other closely similar instances, and a number of these are accompanied by barometric fluctuations of the same general magnitude as that recorded on March 23 to 26. There is therefore at least good presumptive evidence of the passage of other cyclones across Greenland during the observation year 1930-1931. That they have not been identified with certainty is due probably to the lack of closely correlatable data from the three stations.

Although there can be no question that the ice sheet in the vicinity of the Ice Cap Station (of the British Arctic Air-Route Expedition) is alimented by cyclones, yet, as to the tracks followed by these disturbances meteorologists are not entirely agreed. From British synoptic charts, MIRLEES [1932] of the Meteorological Office in London deduced that the two great snow storms recorded at the Ice Cap Station on January 30-31 and on February 18-20, 1931, probably had crossed Greenland from west to east. Georgi, on the other hand, holds that these storms traveled up along the east coast of Greenland. He maintains, very reasonably, that the southward tapering mass of Greenland acts, in a measure, as a switch for cyclones, shunting those that come from the southwest up along either the west or east coast [GEORGI, 1933].

Hobbs has reproduced Georgi's charts showing the probable tracks of the two disturbances in question up along the west coast [HOBBS, 1944, pp. 78-79] and has seized upon this interpretation to bolster up his argument that cyclones can not pass over Greenland. It is to be noted however, that Georgi did not refer to the Eismitte records for the two periods in question, and that omission greatly weakens his case. Because of the strategic position of Eismitte, its meteorological records might be expected to furnish the decisive evidence. Perhaps Georgi did not feel free to refer to the Eismitte records because they were not published at the time that he wrote. What ever the reason for ignoring them, it should have been stated.

Examination of Georgi's own day-to-day records at Eismitte and his graph sheet reveal, as a matter of fact, that the period January 26-30 was one of the stormiest of the whole winter. Strong southeasterly and south-southeasterly winds brought snow day after day, until on January 31 the wind suddenly veered around to the north-northwest, bringing partly clear skies and a drop in temperature. The north-northwesterly winds, moreover, extended up to an altitude of five km above the Ice Cap, or eight km above sea level. To the junior author it seems hardly conceivable that this could have happened without the passage of a cyclone clear across Greenland. He therefore would be inclined to accept Mirlees' interpretation rather than Georgi's. The storm of February 18-20 presents a more doubtful case. The Eismitte records show only a moderate barometric fluctuation and no round-the-compass shifting of the wind. Georgi's interpretation of this case therefore is possibly better than Mirlees'.

That there is inherently nothing to prevent strong and high cyclones from leaping over Greenland is, further, to be inferred from Georgi's own statement that some of the cyclones measured by him in the area between Greenland and Iceland reach heights "up to 10,000 meters." Cyclones of such great height, coming from the west, would hardly be stopped by the Greenland barrier, whose altitudes are for the most part under 3000 meters. It must not be overlooked, in this connection, that mountain barriers of comparable height in other parts of the world often fail to block strong cyclones. The Sierra Nevada of California, which rises 10,000 to 14,000 ft above its western base, is a well known example. WEGENER [1939a, pp. 99-100] in his supplementary remarks about the Eismitte records in any event was fully justified in saying, "The observations at Eismite indicate that low-pressure and high-pressure areas can wander across the inland ice of Greenland, in spite of its height of 3000 meters.

As regards the repelling effect of the downslope winds over the Greenland Ice Sheet, this is not nearly as powerful as Hobbs imagines. Georgi does not even refer to it. The aerological observations at Eismitte, at the West Station of Wegener Expedition, and at the two auxiliary stations in Kamarujuk Fiord and at Umanak, show that those winds comprise a layer of chilled air as a rule less than 500 m deep that loses its dynamic force a short distance out from the coast. In a broad view of the atmospheric movements over Greenland this shallow layer is no more than a thin film on the surface of the Ice Sheet. The meteorologists of the Wegener Expedition commonly refer to it as "die Kaltlufthaut" - literally, "the cold air skin" [WEGENER, 1940, pp. 29-30].

Georgi, meanwhile, deserves credit for drawing attention to the important role which the cyclones along the east coast of Greenland play in the alimentation of the Ice Sheet. It is too generally assumed that all of the moisture that falls upon the ice sheet comes from the west coast. He makes it clear that much of it comes also from the east coast - a very significant fact considering that the main divide of the Greenland Ice Sheet, from Cape Farewell up to about the 73rd parallel is much nearer the east coast than the west coast. A comparison of the meteorological records of the West and East Stations of the Wegener Expedition indeed shows that cyclonic activity is stronger and more frequent on the east coast than on the west coast. GEORGI [1933, p. 344] further suggests that the stormy zone between the main divide and the east coast owes its heavy precipitation to the interference of the "warm and wet air masses" that come from the west "with the stormy and perhaps colder rear of the east Greenland lows."

In connection with the foregoing reference to the influence of cyclones along the east coast of Greenland, mention seems appropriate of the weather reports of the two British surveying expeditions that have penetrated the lofty mountain region which culminates in Mount Forel (11,500 ft) and, as far as now known, comprises the highest part of Greenland, though close to the east coast, and an American Ice-Sheet outpost.

The British Arctic Air Route Expedition of 1930-1931--Though located exactly on the ice divide, this expedition nevertheless attained an altitude of only 8150 ft, being situated in the broad saddle between the lofty summit region about Mount Forel and the South Greenland Dome. It consequently was only 150 mi distant from the east coast and within the zone that is influenced by the frequent cyclones that travel up along the coast. The station was operated for nearly eight months, from September 8, 1930 to April 26, 1931, and its records therefore cover the same winter months as those of the Eismitte station.

The downslope winds came as a rule from northwesterly directions but the snow storms were brought by strong southerly or southeasterly (upslope) winds. Clearing weather was accompanied by fierce, cold gales from the north - doubtless gales in the rear of eastward departing cyclones, intensified by the resumption of the downslope winds. Periods of good weather and of bad weather alternated with one another in an entirely normal manner, and there was no indication of anything like a perpetual or dominant anticyclone, although the station lay within a short distance of the highest dome of the Greenland Ice Sheet.

The Stephenson party of the same expedition, though giving but scanty weather data, nevertheless significantly reports frequent difficulty in identifying peaks sighted from instruments stations 30 mi apart along their traverse, because on their way from point to point they traveled much of the time "in low clouds or falling snow" [STEPHENSON, 1932, p. 12]. Such conditions clearly indicate cyclonic rather than anticyclonic weather.

British Trans-Greenland Expedition of 1934--Of particular interest are the meteorological records of the British Trans-Greenland Expedition from June 18 to September 2, 1934, for the route of that expedition lay approximately along the 70th parallel, that is, over the same part of the ice plateau on which Eismitte was situated, but about 100 mi farther south. The expedition was favored by much good weather on its long trek up the west slope of the ice sheet, but was repeatedly delayed by snow storms while in the summit region near Mount Forel, and as a consequence was unable to complete its mapping program. It reported not less than 13 days of snow precipitation in July and eight in August, a total of 21 days of stormy weather out of 62. Rime was observed on only three days in July and on one day in August. Ice spicules occurred on four days in July and on two days in August. Needless to say, these latter condensation products represented no more than a "trace" of moisture. "The outstanding point in this tabulation," says LINDSAY [1935b, p. 245], "is the number of days (that is, 13 in July) during which snow fell, a very high percentage for midsummer on the ice cap, but which corresponds with the observations taken at Eismitte during the summer of 1931." The bad weather that interferred with the party's activities has been tentatively explained by C. E. P. Brooks [LINDSAY, 1935b, pp. 245-246], the noted British meteorologist, as follows: "On June 23, a barometric depression over Labrador moved northeastwards, and from that date until August 2, most of Greenland came under the influence of a series of disturbances of moderate intensity centered over the coasts or the neighboring seas."

That the members of the expedition were, like those of the Wegener Expedition, very much disappointed in the weather conditions which they met with at the top of Greenland, is readily evident from these passages by Lindsay [1935a, pp. 400-401]: "The party while on its way southwestward through the lofty country between Scoresby Sound and Mount Forel toward the end of July experienced a gale that lasted for three days and three nights, the wind never dropping below 30 mi/hr. We were by this time thoroughly disgusted with the weather, for during the eleven days that we had spent in this region less than three had been fine."

Again, [LINDSAY, 1935b, p. 245], complaint is lodged against the most misleading attribute of the hypothetical anticyclone: "It is of interest that in July, at the highest part of the crossing, winds of force four and six (Beaufort scale) were observed and that there was no period of calm at that time. This is noteworthy in view of the old hypothesis that there would be no winds at the center of the ice cap."

Camp Watkins (1933)--Highly significant, further, are the weather data from Camp Watkins, the Ice-Sheet outpost which the Michigan Pan-American Airways Greenland Expedition maintained for the seven weeks from July 2 to August 19, 1933, in conjunction with its base station Peary Lodge, on the Nugssuak Peninsula, for they show that rain and snow can occur in midsummer even in the interior of northern Greenland.

Camp Watkins was situated in latitude 74′ 40″ N, longitude 47′ 30″ W, about 170 mi east of the western border of the Ice Sheet and at an altitude (barometric) of 8840 ft. It was estimated to be less than 100 mi west of, and only about 500 ft lower than the main ice divide as mapped by Koch and Wegener on their crossing in 1913.

Cyclonic activity diminishes northward along both the west coast and the east coast of Greenland, and it may be presumed therefore, that the station was in a region where anticyclonic conditions such as Hobbs postulates would be more likely than in central Greenland. It lay undoubtedly within the "cold central area" where according to the glacial anticyclone theory, the Ice Sheet received the bulk of its nourishment in the form of ice spicules and hoar frost sublimated from the air brought down from the upper troposphere by the central downdraft in the glacial anticyclone. The observations at Camp Watkins reflect only midsummer conditions, yet they are valuable for they leave no doubt in the writers' opinion as to the nature of the processes whereby this north-central part of the Ice Sheet is alimented, nor of the character of the atmospheric movements that are involved.

The katabatic winds which prevailed during clear weather, came from the east-southeast, being deflected toward the right of the westward downslope direction. They were light and frequently preceded strong southerly and southwesterly (upslope) winds that brought much snow and relatively high temperatures. These southwesterly storm winds had velocities of over 20 mi/hr. "The highest velocity recorded was 38 mi/hr. Gust velocities of 50 mi/hr were not uncommon." The highest temperature reading on July 18 was -1.7°C. On that day there was rain with a temperature of -2.2°C. On the way to Camp Watkins the party experienced another rain, with an air temperature of -5.5°C. "There must have been a considerable inversion of temperature," wrote BELKNAP [1941, p. 181]. He stated that after that rain "we found an ice crust on the surface of the snow until we were a hundred miles from the margin." Surely that rain was not a product of the glacial anticyclone, but was brought by maritime air masses riding up on the Ice Sheet over the thin inversion layer.

He gave prominence to the repeated occurrence of ice spicules descending from shallow patches of so-called "fog." "Sometimes they are undoubtedly important sources of nourishment for the glacier, since, when present, they are constantly being precipitated." But that statement loses much of its impressiveness when it is learned elsewhere [HOBBS, 1944, p. 91] that snow fell at Camp Watkins on 22 days out of 49, that is, on 45 per cent of the total number of days of the occupancy of the station and during that time 14 inches of snow [BELKNAP, 1934, p. 216] accumulated at the bamboo splints that had been planted for the purpose of measuring the accretion of snow at the surface of the ice sheet. What proportion of the 14 inches that accumulated might have been due to direct precipitation and what proportions to drifting, to hoar frost, and to ice spicules respectively, the report does not mention. But from the statement of DEMOREST [1941, p. 775] that "several strong blizzards blew out of the southwest, leaving considerable quantities of snow," it may safely be inferred that the bulk of the accumulated 14 inches consisted of real snow, in part directly precipitated, in part drifted.

In regard to these matters the conditions reported from Camp Watkins are strictly analogous to those reported from Eismitte.

Conclusions concerning Ice-Sheet weather--It might be countered perhaps that the summer weather observed at Eismitte was abnormal and not representative of average years; but that argument would be difficult to sustain, for the Eismitte records cover parts of two summers and these were closely alike, as is clear from a glance at Georgi's graph sheet. To support the argument, therefore, it would be necessary to show that the summers of 1930 and 1931 by a coincidence were both unusual and, indeed, unusual in the same sense and the same degree. The authors are not aware that this has been demonstrated; moreover, comparison with the weather conditions in other years, as reported by other expeditions, some of which have been briefly cited in this paper, reveals that in every case snow storms were encountered in central Greenland during the summer months and that, in general, clear weather and storms occurred in alternation. The occurrence of several snowstorms on the ice cap is, in fact, admitted by Hobbs himself, and he mentions that they sometimes keep the expeditions immobilized for several days, or even for more than a week at a stretch [HOBBS, 1944, p. 75].

From all this it may properly be concluded that Hobbs' picture of essential perpetual anticyclonic conditions at the top of the Greenland Ice Sheet is wholly misleading and is contradicted by the facts as they now are known. To those who would travel across the Ice Sheet, whether on foot or by air, his doctrine holds out false promises of predominantly fair weather with light winds; but in reality such favorable conditions occur only intermittently, for periods considerably less than 50 per cent of the time taking the year as whole.

Inconsistencies of the theory--The observational data cited above furnish, in the writers' opinion, sufficient and conclusive proof that the Greenland Ice Sheet is nourished primarily and almost wholly by cyclones, yet it seems appropriate to draw attention also to certain evidences that are inherent in the physiography of Greenland. These physiographic evidences have been completely overlooked by Hobbs, and indeed no mention of them is to be found in the literature, in so far as it is known to the writer. A full discussion of them and of their bearing on the problem of the origin of the Ice Sheet is out of the question here; only a brief sketch must suffice.

Of prime importance is the general configuration of the Ice Sheet itself. It consists not of a single ovoid dome stretching with unbroken, sweeping profile curve the whole length of Greenland, but of two distinct dome-shaped masses separated by a saddle nearly 100 mi wide and more than 1000 ft deep (see Fig. 1). That saddle lies to the northwest of Angmagssalik and by the British Arctic Air Route Expedition was selected as the logical passage for trans-Greenland flights. In it the Expedition established its Ice Cap Station. It has an elevation of about 8000 ft and is completely covered with snow and ice. To the south of this saddle rises the lesser or what may be called the

South Greenland Dome, which attains an altitude of 9200 ft and measures 400 mi in length from north to south. To the north of the saddle is the main mass of the Greenland Ice Shield, which rises rather abruptly to altitudes over 10,000 ft and extends northward a full 1000 mi, flattening by degrees towards its northern margin. But even this huge mass is not a simple ovoid dome; it culminates in two domes that stand 300 mi apart and rise each of them by gentle slopes some hundred of feet above the intermediate stretch of ice plateau. The southern dome, situated a short distance to the north of Mount Forel (and here provisionally called Forel Dome), is of relatively small extent but is the higher of the two. According to the corrected aneroid readings of the British Trans-Greenland Expedition, it attains an altitude of nearly 11,000 ft above sea level and therefore is probably the topmost eminence on the Greenland Ice Sheet, though still overtopped by Mount Forel itself at 11,500 ft [LINDSAY, 1935b, p. 238]. The northern dome which was crossed by the Høygaard Mehrens Norwegian Expedition of 1931, is at least 10,150 ft high and is very broad and flat. It measures at least 200 mi in diameter and because of its geographic position (72'N, 35'W) may appropriately be called the Central Greenland Dome [MAURSTAD, 1932].

Now the very existence of these three distinct ice domes rules out the possibility of there being only one central alimenting agency such as the "glacial anticyclone" postulated by Hobbs, nor can there be only one grand "centrifugal broom," for such a wind system would tend to eliminate local domes and saddles and would tend to give the Ice Sheet a smoothly curving ovoid or ellipsoidal form, as indicated by HOBBS [1944, Fig. 13, p. 96]. Each of the domes described manifestly is a separate center of snow accumulation and it would therefore by necessary, in order to follow Hobbs' line of thought, to assume the existence of three glacial anticyclones in a row over Greenland. They would have to be rather small sharply localized affairs and they would have to remain fixed in position. Actually, each of the three domes for simple physical reasons has its own system of radiating downsloping winds, and as Hobbs' glacial anticyclone theory is founded on the presence of such winds, that fact might seem to support his theory. But, as already pointed out, the downslope winds are nothing more than gravity currents of chilled, dense air, and are not necessarily caused by an anticyclonic pressure center.

Hobbs has himself stated the reason why, inherently, there can be no tendency toward the maintenance of a persistent high pressure center over a domed ice sheet. It is because the radially outflowing katabatic winds constantly drain off the chilled, dense air contiguous to the ice surface. His own words are, "The centrifugal nature of the motion (of the outflowing surface winds) tends to produce a vacuum above the central area of the (ice) mass, and air must be drawn down from the upper layers of the atmosphere in order to supply the void" [HOBBS, 1911, p. 149].

Over a flat snow-covered expanse conditions unquestionably are propitious for the accumulation of a deep body of cold air and the consequent creation of a more or less persistent standing anticyclone. Such is in fact the case in northern Siberia during the winter months. But over an ice sheet that lies on an elevated mountain mass and is domed to great height, such an accumulation of cold air can not take place because of the constant drainage winds.

Hobbs, curiously, has reversed the argument. He maintains that only over a lofty, domed ice sheet can a glacial anticyclone develop because the declivity of its sloping sides permits the katabatic winds to flow to lower levels. But back of that concept is his confused thinking of katabatic winds as constituting an anticyclone because they have a radial pattern. A radially diverging system of katabatic winds, however, does not in itself constitute an anticyclone, nor does it promote the creation of one; on the contrary, it is very effective in preventing the accumulation of cold air necessary for the production of a cold type anticyclone such as Hobbs' theory requires.

The glacial anticyclone theory has from the beginning stood on an illogical combination of incongruous and incompatible ideas. It seems high time that this confusion be replaced by clear thinking.

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A SIMPLE INTEGRATING DEVICE FOR THE ROUTINE STATISTICAL ANALYSIS OF RECORDED DATA

J. R. Gerhardt

Abstract--The exorbitant amount of labor involved in the routine statistical analysis of recorded data can be reduced considerably by the use of a simple integrating mechanism. For thermistor measurements of temperature in particular, a series of ten electric clocks controlled by contacts on a 50-pole commutator, each of whose poles is equivalent to a temperature change of 0.5°C, indicates the time that the temperature has remained within any of ten successive 0.5°C intervals. Two calculations are all that are then required to obtain the mean and standard deviation of the original record. The maximum response delay of the equipment is about four seconds for temperature changes up to 5°C. Sample statistical analyses are presented.

Introduction--As a result of recent developments and refinements in the various statistical theories of turbulence, research in modern meteorology, and, in fact, in most of the physical sciences, has placed more and more emphasis on the rapid and continuous measurement of the fluctuations of the desired parameters. For micrometeorology in particular, some of the parameters of greatest interest are temperature, moisture, wind speed and direction, and pressure. It is, in fact, only through a detailed analysis of these fluctuation patterns that we can hope to determine such items as the specific structure of turbulence and the mechanisms of transfer processes in the atmosphere.

Unfortunately, however, this selfsame emphasis on continuous recordings leads to an enormous increase in the amount of time required to process or evaluate the raw data. A few minutes record of temperature fluctuations, for example, on an expanded time scale, can require several hours of computation merely to determine the arithmetic mean and the standard deviation of the fluctuations. It was in connection that it was decided to develop an integrating mechanism that would simplify some of the routine statistical computations. While there are currently available electronic circuits for such purposes, it was felt desirable to employ a simpler mechanical-electrical device first in order to test the method at the earliest possible date using inexpensive equipment suitable for field work. The most promising equipment of this nature at the present time appears to be the magnetic tape recorders, but such an installation is admittedly quite a financial undertaking.

Equipment requirements and construction--The basic requirements for an integrating or totalizing mechanism are that it must give a mean value and a standard deviation of the measured parameters over various desired time intervals. The determination of such items as the cross-correlation function between two sets of data, for instance, would be beyond the scope of the present equipment, although, as will be mentioned later, it would be possible to extend the concepts involved to cover this case. The lag and sensitivity of the sensing device and the time constant and summation limits of the integrating equipment are the basic variables in the problem. The response time of the mechanical-electrical device must be at least as rapid as that of the sensing device, or the totalizing process will lag excessively behind and smooth the original fluctuation record. In our particular case, temperature data are currently being taken with Sanborn thermistor rods, approximately 0.5 inch in length between leads and 0.05 inch in diameter. These ceramic resistors have a lag coefficient of between two to three seconds under ventilation speeds of greater than three miles per hour. It was decided that in order best to represent the normal continuous temperature fluctuation pattern by a rectangular type trace (histogram), the temperature summation limits or class width should be no more than 0.5°C. Such a series of temperature steps will usually allow a computation of arithmetic mean and standard deviation based on grouped data that differ from the mean and standard deviation of the original measurements by a relatively small amount. With the larger amplitude of temperature fluctuations near the ground, it might be possible to go to 1.0°C steps, while free air temperature fluctuations should be held to 0.1°C or 0.2°C limits. A somewhat better criterion to determine the number and width of intervals to use in representing a given total range covered would be to divide the total range by a factor of 20 and use that figure as the class width. Although the equipment described here had to use class widths somewhat in excess of these values due to a limitation of ten on the total number of steps available within any range, the resulting statistical errors are not sufficient to invalidate the procedure.

Since the output of the temperature sensing device (thermistor) is normally put through an amplifier for recording purposes, it was decided that the change in amplifier voltage per interval change in temperature would be used to drive a contact over a commutator in such a way that a movement from one pole of the commutator to an adjacent one would represent a temperature change of the desired magnitude. Each pole of the commutator would then be equivalent to the proposed temperature interval of 0.5°C and the movement of the contact over the commutator would trip a series of relays controlling the actions of a series of ten different clocks. The actual driving mechanism used was the motor drive in a Leeds and Northrup recording voltmeter. The clocks were connected in such a manner that the length of time any one clock has been running is exactly the time that the temperature has remained within or above one of ten successive 0.5°C intervals. In this manner, by using a total of 50 poles on the commutator, it was possible to set the total 5°C range expected over any desired portion of the temperature scale so that the number one clock represents the lowest temperature to be expected during a given run. Since this clock then runs continuously, we have a measure of the total duration of any test. To obtain the time that the temperature has remained within each of the ten intervals, it is necessary to subtract successive clock readings.

Calibration--Figure 1 shows an overall view of the entire installation with the Leeds and Northrup meter, Esterline-Angus meter, and clock chassis while Figure 2 is a close-up of the commutator assembly. In this type of operation, the Esterline-Angus meter is recording the original measurement while the clocks are giving an integrated version of the original trace. The maximum response delay of the Leeds and Northrup meter for instantaneous temperature changes up to 5°C is about four seconds, so the totalizing circuit has lag characteristics very nearly identical to the sensing element. Two calibration tests of approximately 20 min duration were made of the equipment. In the first test, successive fixed voltage impulses equivalent to a temperature change of 0.5°C were put into the circuit every 15 sec to cover the total 5°C range. In this case, with the exception of the highest 0.5°C interval, the temperature had remained exactly within each 0.5°C interval for an identical elapsed time of about two minutes and the successive differences between clock readings should have checked this value. Actual readings ran from a maximum of 129 sec to a minimum of 125 sec. In the second test, successive fixed voltage impulses equivalent to a temperature change of 1.0°C were put into the circuit every 15 sec to cover the total 5°C range. In this instance, once again with the exception of the highest 0.5°C interval, the temperature had remained exactly within alternate 0.5°C intervals for an identical elapsed time of about four minutes and had passed instantaneously through the remaining 0.5°C intervals assuming ideal switching. The actual readings varied from 249 to 241 sec for the former set of clocks and from three to 11 sec for the latter.

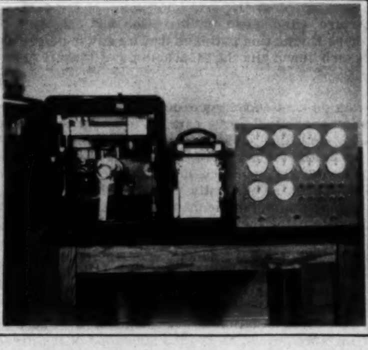
Fig. 1--General view of integrator showing Leeds and Northrup meter, Esterline Angus meter, and clock chassis

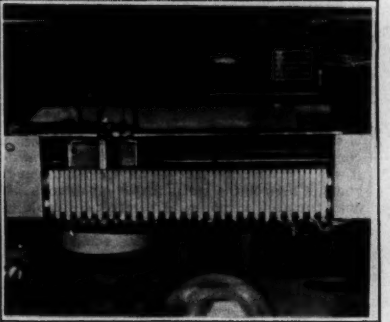
Fig. 2--Close-up of commutator built into Leeds and Northrup meter

Application and sample statistical analyses--Figures 3 and 4 give an example of the operation of this equipment as applied to a typical case. Figure 2 shows a 33-min temperature recording from a thermistor exposed 30 inches above a grass surface on the afternoon of March 7, 1949. The weather was clear and the resulting trace showed a total temperature variation of three to

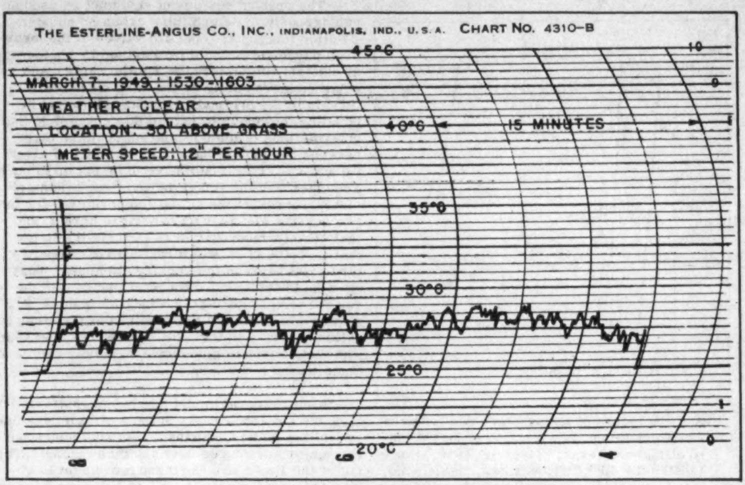

Fig. 3--A recording of the fluctuations of temperature at a single level taken from a shielded thermistor

four degrees C in the range from 25 to 30°C. Figure 4 shows a histogram of the original clock readings and the derived frequency histogram for specific temperature intervals. Two simple calculations using standard statistical procedures for grouped data with continuous variates are than all that are necessary to determine mean temperature and standard deviation. It should perhaps be re-emphasized that the primary usefulness of such a device lies in its ability to reduce materially the time required to make such calculations from original measurements. In this instance, with a circuit capable of responding to changes in temperature with periods of the order of at least ten seconds, it would be necessary to evaluate nearly 200 readings from a magnified version of the original trace in order to determine the mean and standard deviations from the original record.

Figure 5 shows the results of using the equipment to evaluate a sounding made on March 18 where a ten-minute averaging period was taken at nine different levels between one inch and 288 ft. Weather was clear, wind northerly, three to five miles per hour. As is to be expected, the temperature sounding showed superadiabatic lapse rates up to about 60 ft and adiabatic from there on up. The variation of the standard deviation with height is seen to be very close to a straight line on logarithmic coordinates indicating a power law relationship where the standard deviation varies as $Z^{-0.28}$ between 15 and 288 ft.

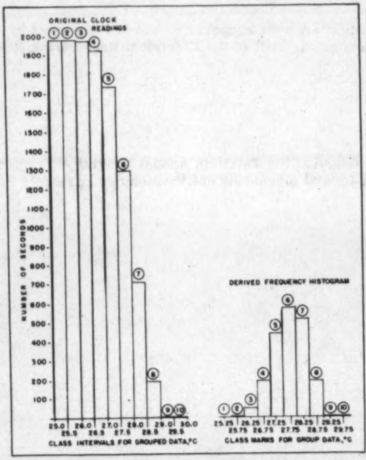

Fig. 4--Histograms showing the temperature distribution taken from integrator data for the temperature recording shown in Figure 3; the calculated mean temperature was 27.73°C and the standard deviation 0.60°C

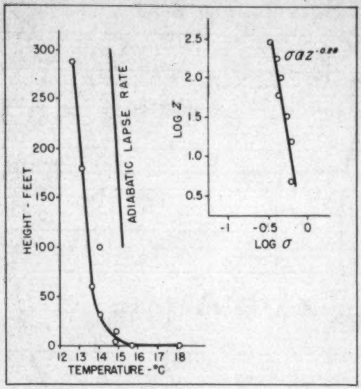

Fig. 5--A record of temperature and temperature fluctuations as a function of height taken at Manor, Texas, March 18, 1949, from 12^h40^m-14^h40^m CST; weather, clear; wind, N 3-5 mph

The present equipment could not be used advantageously in determining cross or autocorrelation functions. Specific values of the measured parameters could be obtained by photography at uniform time intervals, but the same could be obtained more easily by marking off uniform intervals in the original recording. It would be possible, however, to extend this concept so that computations of the correlation could be made between two sets of data if an n^2 array of clocks were used. They would have to be set up in such a manner that the first row and first column of clocks represent the actual temperatures for the two sensing elements as described herein, and that all intermediate clocks indicate the times that a series of known differences of temperature exist between the sensing elements. Thus we would have to know for what per cent of the total run the temperature at one location was ±1, 2, 3.... n intervals above the temperature at the other location, where n is the total number of class widths. The instrumentation becomes unwieldly and overly complicated in a hurry.

A more recent model has been constructed on a purely electronic basis using a circuit developed by Collins Radio Company. This equipment has two major advantages over the other model. The lag of the Leeds and Northrup movement is eliminated, leaving only the 0.5 to 1.0 second lag in clock motion, and it has a scale permitting the use of any desired class width. A change in class width on the mechanical-electrical model requires commutators with different pole thicknesses.

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THICKNESS OF WINTER F-LAYER IN POLAR REGIONS

M. W. Jones

Abstract--The semi-thickness τ of the F-layer, as calculated by the Booker-Seaton method, for the winter months at College, Alaska, decreased from a monthly mean of 24 km for the year 1941-42 to 13 km for 1943-44. This decrease in semi-thickness is coincident with the decrease in total sunspot number. For October to December, 1948, the mean τ was 60 km and the five-fold increase in τ is believed to be coincident with the increase in sunspot number. Contour graphs illustrate the mean diurnal variation in τ.

Introduction--The ionospheric apparatus at College, Alaska, (64° 52.0′ N, 147° 49.0′ W) is the type developed at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and has been described in full by BERKNER [1936, 1939]. The equipment gives one picture of the ionospheric regions every 15 minutes by automatically varying the transmitted frequency from 16.0 mc/sec to 0.5 mc/sec.

As a regular procedure, the records are reduced for the first 15-min period following each hour; that is, one out of every four records is scaled and the data recorded on tabulation sheets.

The semi-thickness τ of the F-layer may be calculated in two different ways. Each of these is based on the method of BOOKER and SEATON [1940] for the determination of true height of maximum ion density of an ionospheric region. The first method is by the use of the formula

$$\tau = (h' - h^M)/\phi(x)$$

where $x = f/f_o$ and $\phi(x) = (x/2)\log_e[(1 + x)/(1 - x)] - 1$. Here h' is the virtual height in the region at which a wave of frequency f is reflected, h^M is the height of maximum electron density of the region (measured at 0.834 times the penetration frequency as found by Booker and Seaton who assumed that the distribution of electrons with height was parabolic), and f_o is the penetration frequency of the region. The second and easier method for the calculation of τ is by use of

$$\tau = h^M - h^m$$

Here h^M is the height of maximum electron density for the region, as above, and h^m is the minimum virtual height of the region. The distribution of electrons with height has been found by many different investigators to approximate a parabolic curve closely and in view of this, h^M can be taken to be a true height.

The minimum virtual height h^m can also be used as a true height for the present study because of the following reasons:

(1) During the winter months at College, the F_1-layer does not separate from the general F-layer; only two ionospheric regions can be distinguished (E and F). Thus, a radio wave is not retarded as when it passes through an intermediate region between the E- and F-layers.

(2) Calculations show that the error introduced in measurements of the minimum virtual height of the F-region by retardation of the wave in passing through the E-layer is negligible (actually less than the error due to scaling). The winter E-layers at College are thin and of low electron density. The second of the two methods listed above has been used for the calculation of τ.

The height of maximum electron density of the F-region was scaled from the traces as a routine procedure from the date of installation of the measuring equipment in July of 1941 until June 1944. At this latter date the scalings of this height were discontinued; they were not resumed until July 1948.

Each month the arithmetic means of the tabulated hourly values for all elements were calculated and recorded. These values give a picture of the average variation of each element throughout the month and also serve as a basis for the prediction of wave propagation conditions for future months. Early in 1945 the median value was adopted instead of the arithmetic mean to serve as an

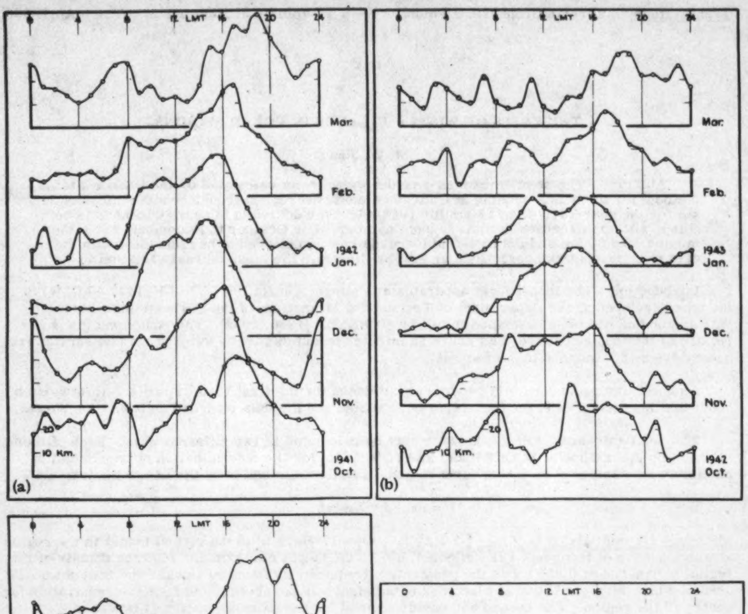

Fig. 1--Semi-thickness of F-layer for winter months at College, Alaska, 1941-44 and 1948-49 index of monthly activity, so as not to place too great a weight on extreme values of any measured quantity.

Values of τ were calculated for winter months (October-March) for the years 1941-1944, and 1948-1949. For the first three periods, the monthly values used are arithmetic means calculated from hourly values of h^m and h^M. For those months available of the period 1948-49 (October-December) the monthly values are median values taken from the hourly observations during the month. Calculations show that τ computed from monthly median values differs very little from τ obtained by using monthly mean values.

Reductions of data for those winters from 1946 to 1948 will be carried out in the future. Traces previous to July, 1946, were shipped to CRPL headquarters in Washington and it is expected that they will be available in the near future so that we may have the complete picture.

Table 1--Semi-thickness of F-layer in km

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Sum	Mean
1941-42	29	25	22	22	21	24	143	24
1942-43	18	16	15	14	18	17	98	16
1943-44	13	15	14	12	13	13	80	13
1948-49	62	60	58	..	..	..	180	60

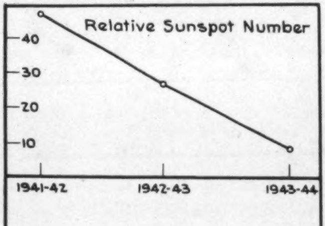

Fig. 2--Mean sunspot number, magnetic character figure, semi-thickness of F-layer for winter months at College, Alaska

Figure 1 shows the diurnal variation of τ for the winter months from October, 1941 through March, 1944, and for October-December, 1948. In general, for all these winters, maximum semi-thicknesses are observed during October, November, and December at about 15^h. The greatest τ occurs earlier in the day in December than in October or March. Minima are not nearly as regular as maxima in these observations but are usually observed during the same months at a time centering around midnight.

Table 1 gives the mean values of the semi-thickness for each month. Each value serves as an index of τ for the different months analyzed. These values enable us to determine any changes in τ from month to month, from one winter to the next, and so on.

In general, the semi-thickness of the F-layer is less in December and January than in October or March. This is probably due to the reduction in intensity of solar radiation incident on the ionosphere above College because of the greater absorbing air mass through which the Sun's rays must pass during the deep winter months at College. It is interesting to note the decrease in τ for any one month for the years 1941 to 1944 and then the leap to high values for the year 1948.

The mean values of the sunspot numbers, American magnetic character figures, and τ for October to March 1941-44 are shown in Figure 2. It is easily seen that as the mean relative sunspot-number decreases, τ decreases also. In other works, as sunspot activity becomes less, the F-layer seems to get thinner. It is expected that τ increased gradually in the years 1944 to 1948 in accordance with increased solar activity and should have reached a maximum at about the time of maximum sunspot number. On the other hand, the American magnetic character figure, C_A, increased for the period as shown in Figure 2.

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COMPARISONS OF SOME AEROMAGNETIC PROFILES WITH GROUND MAGNETIC PROFILES

K. L. Wier

(Published by permission of the Director, U. S. Geological Survey)

Abstract--Typical aeromagnetic total intensity profiles are compared with ground-magnetic vertical intensity profiles over the same geologic structures in the Iron River district in the northern peninsula of Michigan. The magnetic surveys and the pertinent geologic conditions causing the anomalies are briefly discussed. Certain slate and volcanic rocks of Pre-Cambrian age produce the major anomalies; in addition, inversely magnetized diabase dikes cause pronounced negative anomalies. The aeromagnetic profiles are strikingly smoother than the ground-magnetic profiles chiefly because of the merging and attenuation of anomalies with increasing height. The commonly used depth rules applied to the aeromagentic data yield depth estimates that are usually too great.

Introduction--As part of a general restudy of the Lake Superior region, the United States Geological Survey, in cooperation with the Geological Survey Division of the Michigan Department of Conservation, has flown approximately 16,000 mi of aeromagnetic traverses over the northern peninsula of Michigan. A report has recently been issued by the U. S. Geological Survey [BALSLEY, JAMES, and WIER, 1949] in which the results of some of this work are presented in the form of profiles, and similar reports on adjacent areas are in preparation.

For many years, mining companies and other organizations have made extensive ground magnetic surveys in the Lake Superior region. The major purpose of this paper is to present comparisons of typical aeromagnetic profiles with ground profiles so that geophysicists and geologists familiar with the latter can more readily evaluate the aeromagnetic data. Although some of the more important factors that contribute to the differences between aeromagnetic and ground magnetic profiles are discussed, this paper is essentially a presentation of factual information rather than a theoretical or mathematical analysis of the two types of observations.

Nature of the surveys--The aerial surveys were made with an AN/ASQ-3a fluxgate magnetometer [BALSLEY, 1946; BALSLEY, JAMES, and WIER, 1949] at an altitude of approximately 500 ft above ground surface. This height varied from about 400 to 600 ft depending on topography and flight conditions, and because the magnetic detector unit is towed on a cable some distance beneath the plane the height above ground of the actual magnetic mapping was usually less than 500 ft. As described in the reports referred to, the information is recorded as a continuous profile of total magnetic intensity. Vertical component magnetometers were used for the ground determinations, with stations at paced intervals of 100 ft along traverse lines. Most of the determinations were made with an Askania magnetometer with a sensitivity of approximately 35 gammas per scale division, and the remainder were made with a Wolfson magnetometer (model M-1) with a sensitivity of approximately 30 gammas per scale division. The maximum error of the ground observations is about ten gammas. The airborne magnetometer measures variations in the total intensity of the magnetic field, and the ground instruments measure variations in the vertical component. However, in the latitude of northern Michigan, where the magnetic inclination is steep and the magnitude of the vertical component approaches that of the total intensity, the two may be compared without appreciable error.

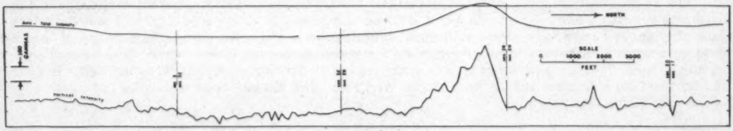

Fig. 1--Part of Aeromagnetic Traverse 93 along west side of Sec. 5, T. 43 N., R. 34 W., and 32, 29, 20, and 17, T. 44 N., R. 34 W., Iron County, Michigan; glacial drift is probably more than 100 ft thick; cause of anomaly is unknown

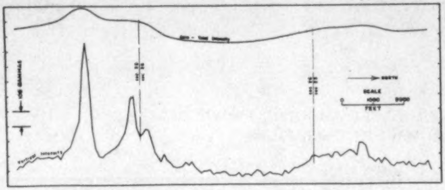

Fig. 2--Part of Aeromagnetic Traverse 101 along east side of Sec. 35, 26, and 23, T. 44 N., R. 35 W., Iron County, Michigan; glacial drift is probably more than 100 ft thick, although greenstone crops out at extreme north end of traverse in Sec. 23; anomalies are probably caused by magnetic parts of greenstone

The anomalies used for comparative study (see Fig. 1-7) were chosen because of accessibility, freedom from extraneous magnetic influences, and ease of establishing the position of the aerial traverse (from the continuous strip film taken during the flight), and because they are reasonably typical of the area. Most are in the vicinity of the Iron River district of Iron County. Some of the ground traverses of earlier surveys by the U. S. Geological Survey were used, but others were run specifically for purposes of comparison. In most surveys, ground traverses were within 25 ft of being vertically beneath the flight paths, and the maximum deviation is probably less than 100 ft.

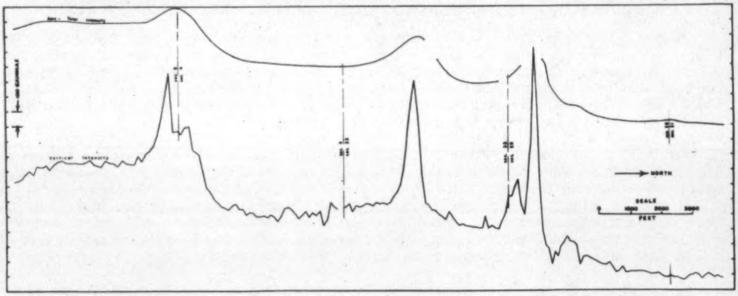

Fig. 3--Part of Aeromagnetic Traverse 85 along east side of Sec. 9 and 4, T. 42 N., R. 34 W., and 33, 28, and 21, T. 43 N., R. 34 W., Iron County, Michigan; glacial drift is probably more than 100 ft thick; anomalies are caused by magnetic slate probably contained in tight synclines

Geologic factors--The rocks causing the anomalies are Pre-Cambrian in age, and, except for late Pre-Cambrian diabase dikes, are of sedimentary or volcanic origin. All have been weakly metamorphosed, with the development of magnetite as a disseminated constituent in certain of the slate and volcanic members. The magnetite rarely exceeds 20 per cent by volume, and the magnetic permeability of the rock is accordingly weak to moderate in comparison with magnetic iron ores. Permanent magnetization appears to be subordinate to magnetization induced by the Earth's present magnetic field. However, the negative anomalies shown on Figure 7 are caused by inversely magnetized diabase dikes, approximately 100 ft thick.

The rocks, including the diabase dikes, are everywhere steeply dipping or vertical, and the strike is generally nearly east. Some of the anomalies (such as those in Figure 3 and the north part of Figures 5 and 6) are above very tight synclines in a magnetic slate. As a result of the intense folding, only one magnetic crest is shown by the compressed two limbs of the structure. The depth to which these synclines of the magnetic slate extend is probably several thousand feet. In general, the form of the magnetic units - beds, tight synclines, and dikes - approaches that of narrow bodies of infinite length and depth.

Most of the bedrock is mantled with galcial drift that varies from few feet to more than 300 ft deep, and the ground magnetic profiles do not actually represent magnetic profiles across the rock surface. As far as information is available, the approximate thickness of the cover is given

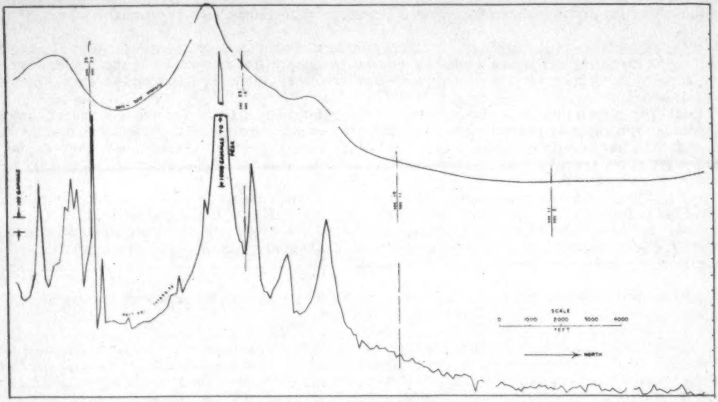

Fig. 4--Part of Aeromagnetic Traverse 102, 1/4 mile west of east side of Sec. 26, 23, 14, 11, and 2, T. 42 N., R. 35 W., Iron County, Michigan; glacial drift is probably less than 100 ft thick along much of traverse; anomalies are caused by magnetic layers in greenstone

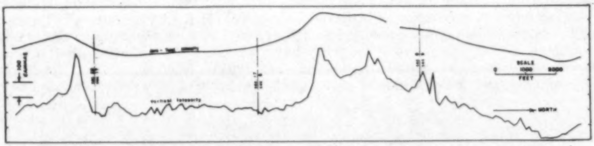

Fig. 5--Part of Aeromagnetic Traverse 89 along east side of Sec. 20, 17, 8, and 5, T. 42 N., R. 34 W., Iron County, Michigan; glacial drift varies from less than 50 ft to more than 200 ft in Sec. 8 and 5; and is probably less than 50 ft in Sec. 20; anomalies in Sec. 8 and 5 are caused by magnetic slate; the one on Sec. 20 by magnetic greenstone

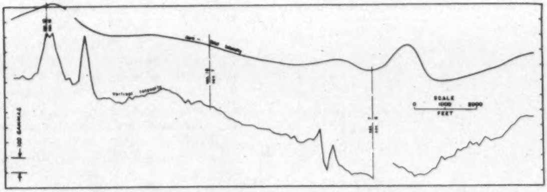

Fig. 6--Part of Aeromagnetic Traverse 93 one mile west of Traverse of Fig. 5 along east side of Sec. 19, 18, 7, and 6, T. 42 N., R. 34 W.; glacial drift varies from less than 50 ft to more than 200 ft; anomalies in Sec. 7 and 6 are caused by magnetic slates, probably in tight synclines; those in Sec. 19 and 18 by magnetic greenstone

with each profile. The effect of the drift cover is to smooth out the irregularities of the ground profiles, and, because of the spreading out of an anomalous magnetic field at increased distance from its source, to reduce the possibility of missing anomalies with ground stations spaced at arbitrary intervals.

Erratic boulders of magnetic rock are not common in the glacial drift. Consequently, it is unlikely that the profiles shown have been appreciably distorted by such erratic effects.

Characteristics of the profiles--A striking feature of all the comparisons shown in Figures 1 to 7 is the irregular and jagged appearance of the ground profiles in contrast to the smoothness of the aeroprofiles. Many factors contribute to this difference, the more important of which are listed as follows:

(1) The ground profile is closer to the source of magnetic disturbance and will record small anomalies and separate magnetic crests that either disappear or merge at greater heights.

(2) The aeroprofile is obtained as a continuous recording with no sharp points, whereas the character of the ground profile depends upon the interval used between stations and as usually plotted is very jagged.

(3) The ground determinations are influenced to a much greater extent by extraneous magnetic fields (such as pipe lines, rails, or boulders of magnetic rock in the glacial drift).

(4) The speed with which the aeromagnetic data are obtained minimizes the effect of magnetic storms, diurnal variation, and instrument drift, all of which are contributing factors to the inaccuracies of ground determinations.

In general, however, the main reason for the difference in smoothness is the greater degree of resolution of individual anomalies at the ground level.

The crest of an aeroprofile may not necessarily be vertically above the anomaly shown on the ground profile. The location of a magnetic peak extended upward depends largely on the orientation of the magnetic body causing the anomaly with respect to the inclination of the Earth's field (assuming, as is the case for most of the anomalies under discussion, that the magnetization of the rock is mainly that induced by the Earth's field and therefore parallel to it). If the dip of the body is the same as that of the inclination of the Earth's field, the crest should be approximately on the extension of the magnetic axis. In the latitude of northern Michigan, the crest of such an anomaly would be shifted about 100 ft south at an altitude of 500 ft. Of much greater importance, however, are the actual errors incurred in locating the positions of the aeroprofiles with respect to the ground. Mostly because of poor base maps on which the control points, were plotted, such errors may be as great as a quarter of a mile in some of the published profiles, although in the illustrations shown here the errors of position are believed to be less than 300 ft. Even under ideal conditions, there are inherent, in the aeromagnetic method and compilation process, errors in location as much as 100 ft.

In many of the figures, magnetic crests of the ground profiles are not clearly reflected in the aeroprofiles. The attenuation of anomalies depends on the size and shape of the geologic body responsible for the magnetic disturbance. Since many of these quantities are practically indeterminable, and since few geologic bodies are of simple geometric dimension or of magnetic homogeneity, it is difficult to evaluate the anomalies quantitatively. In general, however, an anomaly varies inversely as some function of the distance from the magnetic source. For instance, the magnetic field caused by a point pole theoretically would vary inversely as the square of the distance. In most surveys, the small anomalies shown on the ground profiles have disappeared in the aeroprofiles.

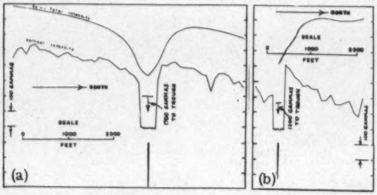

Fig. 7(a)--Part of Aeromagnetic Traverse 77 along east side of Sec. 23 and 14, T. 48 N., R. 34 W.; (b) Part of Aeromagnetic Traverse 93 along east side of Sec. 18, T. 48 N., R. 34 W., Baraga County, Michigan; glacial drift is probably less than 25 ft thick over the anomaly which is caused by inversely magnetized diabase dike

At a point in space the magnetic field is affected by all the surrounding anomalies, and the greater the distance from the magnetic source the greater will be the horizontal spread of the anomaly. At the altitude of the aeroprofiles this results in the merging of anomalies that, at the ground surface, may show as separate crests. Just how the anomalies merge seems to depend on their relative intensity and horizontal separation. In some places two or more crests merge into one definite peak at the higher altitude (see Fig. 4-6); in others, several crests may appear as one major peak with projecting shoulders (see Fig. 2).

Because of this "fanning out" of an anomaly with increasing height, an anomaly adjacent to a traverse can have considerable effect on the aeroprofile and yet hardly influence the corresponding ground profile. This is particularly well illustrated by the north part of the profiles in Figure 6. From detailed ground surveys it is known that adjacent to the traverse path a magnetic high is west of the aeroanomaly shown in Sec. 7 and another magnetic high is east of the aeroanomaly shown in Sec. 6. Although the aeroprofiles clearly show these anomalies, the ground traverse directly beneath discloses only a general magnetic low.

It has been widely believed that magnetic observations at different heights could provide information about a geologic feature that causes an anomaly that would not be available from observations at one elevation alone. However, HENDERSON and ZIETZ [1949] in developing a general continuation process for magnetic fields show that this is not so. They state: (p. 534) "There is inherent in the first-level data the essential information of the higher level . . . . . The use of surface integrals affords a general continuation process and permits detail mapping, on higher levels, of fairly complex fields. It is significant that the process is in no way concerned with the geologic formations disturbing the field."

The depth to the upper pole of the magnetically anomalous body can be determined with reasonable accuracy from the vertical-intensity ground profiles by using standard depth rules (such as those of Hannel, Tiberg, and Thalen, as given in standard text books on geophysical exploration), or by vector analysis using horizontal component or angle of inclination measurements in conjunction with the vertical intensity values. In this area these two methods show close agreement as to depth of the upper pole and, as tested in places of known thickness of glacial drift, indicate that this pole is essentially at the top of the magnetic body.

The aeroprofiles do not seem to be susceptible to analysis by the commonly used depth rules as the depth values obtained are almost invariably too great. One reason for this probably is the increasing relative effect of the lower pole at greater distances away from the magnetic source. Of greater importance is the fact that the aeroanomaly usually is not an isolated one, but is often influenced by adjacent anomalies, so assumptions implicit in the depth rules are no longer valid. A method of estimating depth from total magnetic-intensity anomalies produced by point and line sources which is more applicable to the aero data has been developed [HENDERSON and ZIETZ, 1948]. This method gives more reasonable depth estimates as applied to the anomalies in this area, but usually the depth determinations are still too great. Again the chief difficulty is probably caused by the composite character of most of the aeroanomalies.

Conclusions--The comparison profiles of aeromagnetic and ground-magnetic data show rather striking differences when plotted at the same linear and intensity scale. The major difference is the much smoother character of the aeroprofiles, which is due largely to merging of adjacent anomalies and general decrease in magnetic intensity at the greater altitude. Ground work over a smooth anomaly revealed by the aeromagnetic profiles will frequently resolve the anomaly into several well-defined but closely spaced crests. In a few places, ground work fails to disclose an anomaly beneath the flight line; the existence of the anomaly at the greater altitude is, in these places, due to the spreading effect of anomalies that are adjacent to, but not on the ground traverse.

Depth rules applied to the aeromagnetic data usually give depth estimates that are too great, largely because of the complex character of most aeroanomalies.

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U. S. Geological Survey,
Washington 25, D. C.

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NEARSHORE WATER CIRCULATION RELATED TO BOTTOM TOPOGRAPHY AND WAVE REFRACTION

F. P. Shepard and D. L. Inman

(Contribution from the Scripps Institution of Oceanography, New Series, No. 445)

Abstract--The nearshore circulation in the vicinity of Scripps Beach has been measured by means of very simple devices. It has been found that this circulation is controlled to a large degree by the wave convergence and divergence resulting from the diversified submarine relief outside this gently curving shoreline. The position of rip currents is similarly related to the points of wave convergence and divergence. The existence of strong longshore currents flowing against the direction of wave approach is established. The development of large eddies with vertical axes is discussed. Also the pulsating nature of outflowing rip currents is related to alternating groups of high and low breakers.

Introduction

The cyclic changes of beaches have been under observation in Southern California during the past 15 years. The removal of sand from the beaches during periods of large waves and the bringing in of sand and rebuilding of beaches during periods of small waves have been clearly demonstrated from these studies [SHEPARD and LAFOND, 1940]. However, the mechanism by which the waves and currents produce this alternate onshore and offshore movement and the nearshore water circulation associated with wave motion has been poorly understood. Model experiments using dye in tanks [BAGNOLD, 1947] showed that there was a net offshore drift from mid depths to the water surface, and an onshore drift near the bottom. On the other hand, observations by the BEACH EROSION BOARD [1933] near the Long Branch Pier in New Jersey using a floating vertical staff and weighted croquet balls suggested that there was a shoreward movement of water near the surface, and a net seaward drift near the bottom. The observation of rip currents [SHEPARD et al, 1941] has suggested that a considerable amount of circulation takes place around vertical axes.

As one step in the investigation of the exact nature of these water movements a series of simple tests has been made in the vicinity of Scripps Institution. These tests appear to give good evidence of the general nature of nearshore circulation in an area where there is wave refraction resulting from bottom irregularities. The same general pattern has also been observed in another area of similar bottom topography.

The tests included observations in the surf zone using dye for surface movements and a weighted ball for movements along the bottom. Outside the breakers, observations were obtained by the use of surface floats and by triplanes attached to marker buoys and suspended at various depths. Observations of the currents have been correlated with breaker heights, wave periods, and changes of water level along the shore.

Description of the area

The observations were made off Scripps Beach, which lies just north of La Jolla Point. The coast here is relatively straight, and a sand beach extends for a mile, terminating to the south at the La Jolla Beach and Tennis Club and to the north at Scripps Institution (see Fig. 1). The straightness of the coast is in great contrast to the adjacent submarine topography. On the sea floor two submarine canyons come in to about 700 ft from the low tide shoreline and extend diagonally out from the coast and join a mile from shore. In between the canyon heads there is a gently sloping shelf with an average seaward inclination of 1.3° out to the canyon rims (see Fig. 2 and 3). This shelf is sand-covered in contrast to the canyons where rock and alluvial cliffs are exposed and where the floors are covered with a mixture of sand and silt. Examination of the details of the shoreline (see Fig. 1) shows that there are rocky points south of each of the canyon heads. Less conspicuous sand points are present on either side of the heads of La Jolla and Scripps Canyons. A slight submarine continuation of the sand points is shown by the soundings and is also clearly indicated by the wave-convergence pattern. Almost half way between the two canyons the beach has a concavity

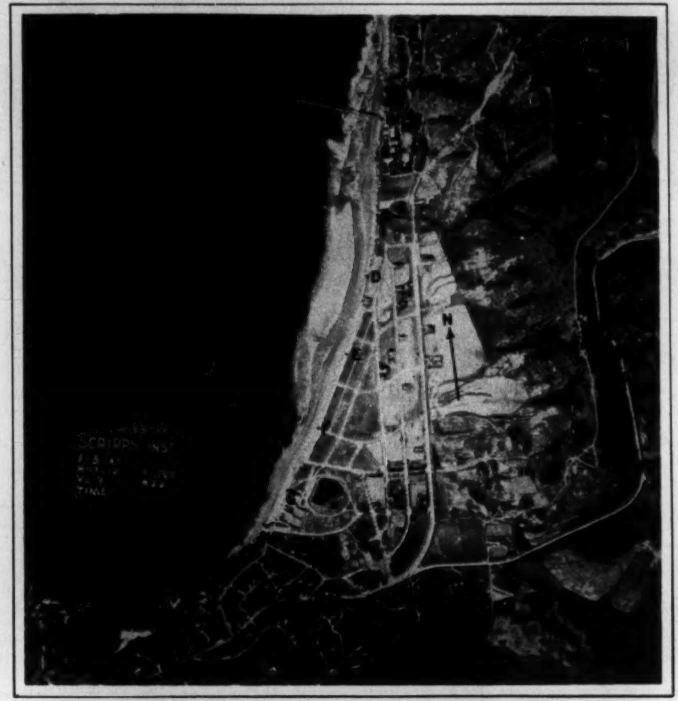

Fig. 1--Scripps Beach at La Jolla, California; note the narrow surf zone at the canyon head, F to G; the wide surf zone at the wave convergence, C to E; and the rip currents on both sides of the convergence at B and E

which is particularly impressive after the storm season.

The advance of wave crests towards the shore in the area develops a pattern in rough conformity with the submarine topography [MUNK and TRAYLOR, 1947]. A refraction diagram for waves of 14-sec. period approaching Scripps Beach from the west-northwest is shown in Figure 2. The wave crests near the outer breaker line are convex to the shoreline at the canyon heads and cancave between them. The effect of this shoreward bend, or divergence, at the canyon head is to dissipate the energy of the waves and to produce very low breakers. Between the canyon heads the waves converge, causing a concentration of the wave energy. During long period waves the breaker heights at the convergence are several times higher than those at the canyon heads.

Methods and devices

The current-measuring devices used for these preliminary studies of the circulation were all of extremely simple construction. Triplanes (current crosses) were built for measurements outside the breakers. These consist of two tin plates 16 inches square which were crossed at right angles and strengthened by wooden crosspieces. The triplanes were suspended by cod line from surface floats. The latter are small and float high in the water so that the large surface of the

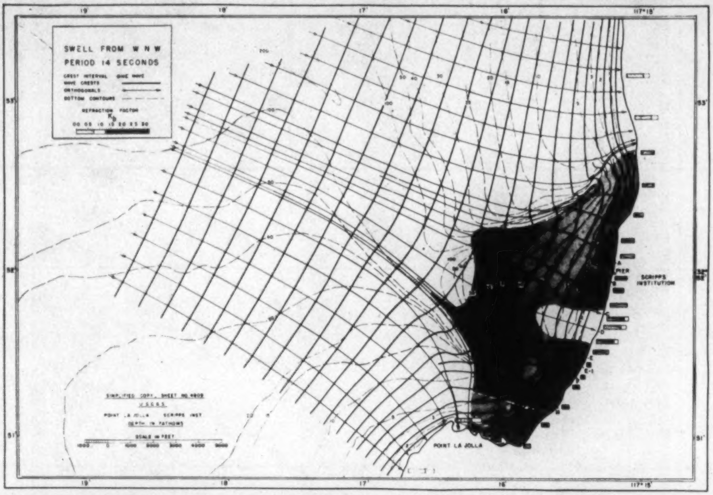

Fig. 2--Refraction diagram for 14-sec waves from the west-northwest; the shaded regions indicate zones of divergence; the lengths of the rectangles opposite the shore stations are proportional to the refraction factor, and thus indicate the variation of breaker heights along the beach [from MUNK and TRAYLOR, 1947]

triplane is much more affected by currents than is the surface float. The depth at which the current is measured is determined by the length of cod line below the float. If there were high winds the surface float would be considerably influenced by them, but no operations were made under these conditions. Also if there were no appreciable currents at the triplane depth the surface float would control the movement while the triplane would act as a sea anchor. This condition would produce movement in the same direction as the surface float but at only a small fraction of the speed. Since this condition has not yet been observed, it will be assumed that the triplanes were the controlling factor in the observations.

In general, triplanes were set out near the bottom and at mid depths, while surface currents were measured by observations on a drift bottle. The three devices were placed out in close proximity, and the position was obtained by horizontal sextant angles, which give an accuracy to within a few feet because of the nearby, accurately located stations. After a few minutes of drift the boat was nosed alternately up to one float after another, and the time and position obtained at each contact. When the floats were moving toward shore, care had to be taken to pick them up before the triplanes hit bottom. Upon getting into shallow water the triplanes ground during the period of outflow in wave troughs and float free during the inflow accompanying crests, the result favoring shoreward movement. During the operation soundings were obtained with a lead line at each observation point so far as was possible.

For operations in the surf zone several systems were used. The most practical combined observing the surface current with sea-marker dye and measuring the bottom flow with a weighted ball. A nine-inch volley ball was used, filled with water and just enough mercury to make it slightly heavier than sea water. Two observers took a position just inside the breaking waves, while a third observer remained on shore to time and record their observations. The starting points for the observations varied in depth from 2.5 to 3.5 ft. During the observations, one offshore observer remained as closely as possible at the point where the ball was released. At the same time that the ball was released, some dye was thrown into the water and a signal was given to the shore observer. At the end of a 15- or 30-sec period, at a signal from the shore, the man following the ball picked

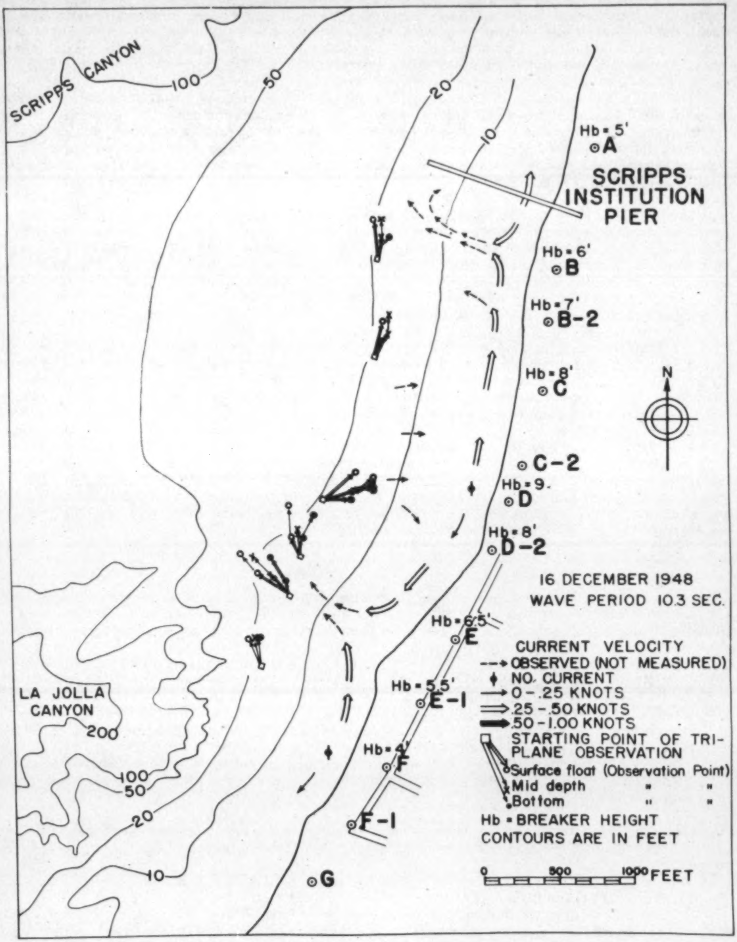
SCRIPPS CANYON
100
50
20
10
Hb = 5'
A
SCRIPPS INSTITUTION PIER
Hb = 6'
B
Hb = 7'
B-2
Hb = 8'
C
N
C-2
Hb = 9.
D
Hb = 8'
D-2
16 DECEMBER 1948
WAVE PERIOD 10.3 SEC.
Hb = 6.5'
E
CURRENT VELOCITY
OBSERVED (NOT MEASURED)
NO. CURRENT
0 - .25 KNOTS
.25 - .50 KNOTS
.50 - 1.00 KNOTS
STARTING POINT OF TRIPLANE OBSERVATION
Surface float (Observation Point)
Mid depth " "
Bottom " "
Hb = BREAKER HEIGHT
CONTOURS ARE IN FEET
0
500
1000 FEET
Hb = 5.5'
E-1
Hb = 4'
F
F-1
G
LA JOLLA CANYON
200
100
50
20
10

Fig. 3--Typical nearshore circulation pattern at Scripps Beach resulting from waves with a period of ten seconds or greater and a northerly flowing coastal current; the longshore and rip currents were measured with the weighted ball, and the currents outside of the breaker zone with surface floats and triplanes; note the diverging currents off stations D and F, and the rip currents off B and E-1 it up. The line attached to the ball, which was marked in fathom lengths, was tightened so that the distance traveled by the ball could be ascertained. One of the observers in the water noted the distance and the direction of movement of both the ball and the dye. The use of dye instead of a drift bottle for surface currents was found advisable because the drift bottle was almost invariably carried shoreward by the surfboard action of the waves.

In conjunction with some of the ball and dye operations, continuous visual observations were made of the breaker heights and of the variation in water level near shore. The latter was obtained by driving a pole calibrated to tenths of a foot into the sand and having an observer call off the average elevation of the water for each ten or 15-sec period. The breaker heights were obtained by noting the height each breaker rose above mean water level, using the height of eye above mean water level and the horizon as an index.

Making use of days with no wind, a series of small wooden floats numbered from one to 50 was dropped from a boat at intervals of about 130 ft along a line parallel to the shore. The location of each float was obtained as it was dropped from the moving boat. After dropping the last float, the boat returned to the starting point of the line, and the new position of each float was obtained in succession. This operation was continued until the floats neared the breaker zone or were lost. Later a search was made for the floats on the beach, and on one occasion the time of arrival of a considerable number of them was determined.

All of the above operations were correlated with the wave meters installed at Scripps Institution. Wave periods and heights (in addition to the visual observations) were obtained from a Mark III sub-surface pressure recorder [FOLSOM, 1949]. This instrument is mounted on the ocean floor 900 ft off the end of the Scripps Institution Pier in water 40 ft deep. It records surface waves ranging in period from approximately four to over 20 sec.

In addition to the Mark III wave meter, a tsunami recorder [MUNK et al, 1948] was used during the extended ball and dye observations near Scripps Pier. This latter instrument is mounted on the end of the pier and is designed to record low amplitude surface waves with periods ranging from approximately one minute to four hours. The instrument was helpful in that it indicated the presence of waves whose periods coincided with the period between high wave groups as recorded by the Mark III unit and by visual observation of breaker heights.

Terminology

In order to avoid confusion we are suggesting definitions for the various currents associated with nearshore water circulation. Where possible the terms in common use have been retained. However, owing to ambiguity in older usage, we have found it advisable to redefine certain terms.

The circulation pattern observed near La Jolla appears to be the result of at least two current systems: (1) the nearshore system associated with wave motion in and near the breaker zone, and (2) the current system which is more pronounced in the deeper water adjacent to the surf zone. The latter, which will be referred to as coastal currents, is not related genetically to the waves and the resulting surf. In general, the coastal currents parallel the shoreline and have a relatively uniform velocity (as compared with the rapid fluctuations encountered in the nearshore circulation system). The coastal currents may be composed of one or more of the following; currents (or local eddies) related to the distribution of mass in the oceanic waters, wind-driven currents, and tidal currents.

The nearshore current system is associated directly with the action of waves in and near the breaker zone and with the configuration of the shoreline. The circulation in this system may be subdivided into:

(1) Shoreward mass transport of water caused by wave motion.

(2) Longshore currents or movement along the shore, largely confined to the surf zone. These currents are caused by (a) waves approaching the beach at an angle, and (b) the rise in water level due to the shoreward mass transport by waves.

(3) Seaward return flows compensating for the shoreward mass transport of water by waves.

(a) Rip currents or seaward moving water masses restricted to relatively narrow lanes.

(b) Uniform seaward return flow. There may be processes other than rip currents by which water is returned seaward. MUNK [1949a], in adapting the solitary wave theory to the surf zone, suggests that in addition to rip currents, the shoreward mass transport is compensated by a uniform seaward return flow. This flow would differ from rip currents in that it acts uniformly from the surface to the bottom and is of equal intensity at all points along a straight beach not affected by wave refraction. Superposing this flow on the mass shoreward transport of water due to waves would result in a net shoreward drift near the water surface and a net seaward drift along the bottom. Model experiments have given varying results regarding the seaward return flow. Tank experiments at the Imperial College of Science and Technology [BAGNOLD, 1947] indicated a net seaward drift from the surface to mid depths and a net shoreward drift along the bottom. Experiments by the BEACH EROSION BOARD [1933] suggest a net seaward drift near the bottom and a net shoreward drift near the surface.

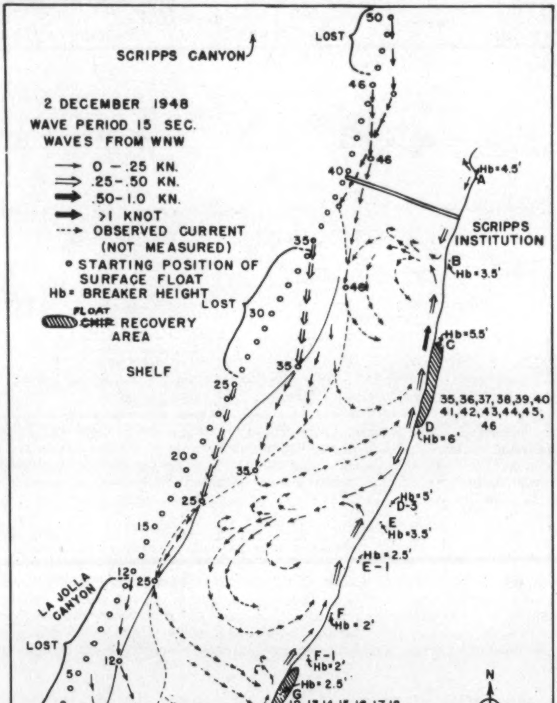
SCRIPPS CANYON
LOST
50
46
46
40
2 DECEMBER 1948
WAVE PERIOD 15 SEC.
WAVES FROM WNW
0 – .25 KN.
.25–.50 KN.
.50–1.0 KN.
>1 KNOT
OBSERVED CURRENT (NOT MEASURED)
STARTING POSITION OF SURFACE FLOAT
Hb= BREAKER HEIGHT
FLOAT ~~CHIP~~ RECOVERY AREA
Hb=4.5'
A
SCRIPPS INSTITUTION
B
Hb=3.5'
35
46
LOST
30
Hb=5.5'
C
SHELF
35
25
35,36,37,38,39,40
41,42,43,44,45,
46
D
Hb=6'
20
35
25
Hb=5'
D-3
15
E
Hb=3.5'
Hb=2.5'
E-1
12
25
LA JOLLA CANYON
F
Hb=2'
LOST
F-1
Hb=2'
12
5
Hb=2.5'
G
12,13,14,15,16,17,18
19,20,21,22,23,24,25
N
12
1130 PDT
G-2
H
0
500
1000
FEET
1215 PDT

Fig. 4--Typical nearshore circulation pattern resulting from waves with period greater than ten seconds, and a southerly flowing coastal current; the longshore currents were measured with the weighted ball, and the currents outside of the breaker zone by a series of 50 surface floats dropped along a line parallel to the shore; note that floats 1-11, 26-35, and 47-50 were not recovered; the latter two groups moved seaward during increased rip velocities off stations B and E-1 at 12^h15^m

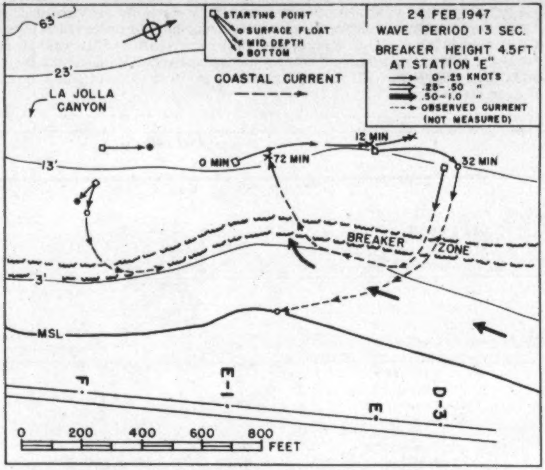

Fig. 5--"Eddy-like" path of a triplane placed at mid depth off a rip current at station E-1; the triplane completed the circuit in 72 min., having traveled approximately one-third mile

There is no sharp division between areas where the nearshore current system is predominant, and those where the coastal currents predominate. With waves of low amplitude and in sections where the beaches are steep it is possible that the effects of the coastal currents may be observed on the beach. On the other hand, under extreme conditions of high waves, the nearshore circulation may completely mask the effects of any existing coastal current out to distances of several thousand feet from shore.

General circulation patterns

Combining the various types of measurements of the circulation at Scripps Beach (discussed above) with a considerable amount of observational data gathered over a long period of time, we find that there are several common circulation patterns. The pattern depends on the following factors: (1) the wave period and height; (2) the direction of deep water wave approach; and (3) the direction of the coastal current. The four general patterns which are most typical of this area are discussed below.

Swell and canyon effect--In the case of a swell having a period exceeding, say, ten seconds, the direction of deep water wave approach does not appear to be an important factor in determining the general circulation pattern because of the effect of wave refraction over the diversified submarine topography [MUNK and TRAYLOR, 1947]. For these longer periods the topography results in great contrast in breaker height, divergence and very low waves at the canyon heads, and convergences and higher waves over the shelf between the canyons. The point of extreme convergence shifts somewhat up or down the beach depending on the angle of approach of the deep water waves. Figures 3 and 4 show the typical pattern of longshore currents which accompany longer period waves. At the point of convergence the longshore currents are weak and variable. However, away from the wave convergence the longshore currents flow with considerable velocity to the north on the north side and to the south on the south side. It should be noted that these currents flowing away from the zones of wave convergence are actually flowing against the direction of wave approach at the breaker line. This forms an important exception to the general rule for straight beaches with parallel contours, as outlined by PUTNAM, MUNK, and TRAYLOR [1949]. These diverging currents imply that water is moving shoreward at the wave convergence, and the measurements show that this is indeed

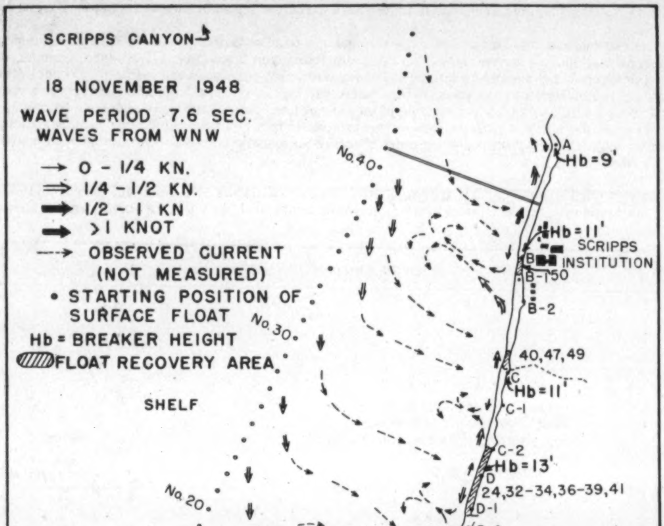
SCRIPPS CANYON
18 NOVEMBER 1948
WAVE PERIOD 7.6 SEC.
WAVES FROM WNW
0 - 1/4 KN.
1/4 - 1/2 KN.
1/2 - 1 KN
>1 KNOT
OBSERVED CURRENT (NOT MEASURED)
• STARTING POSITION OF SURFACE FLOAT
Hb = BREAKER HEIGHT
FLOAT RECOVERY AREA
SHELF
No. 40
No. 30
No. 20
No. 10
No. 1
LA JOLLA CANYON
A
Hb = 9'
Hb = 11'
SCRIPPS INSTITUTION
B
B-150
B-2
40, 47, 49
C
Hb = 11'
C-1
C-2
Hb = 13'
D
24, 32-34, 36-39, 41
D-1
D-2
15, 22, 26, 27
29-31
D-3
Hb = 9'
E
Hb = 6'
E-1
8-10, 12, 13, 16
19-21, 23, 25
F
Hb = 5'
2-5, 7
F-1
Hb = 4'
1, 6
G
G-1
G-2
BEACH CLUB
N
0 500 1000 FEET

Fig. 6--Typical nearshore circulation pattern resulting from waves less than ten-second period approaching normal to Scripps Beach, and a southerly flowing coastal current; note the numerous rip current zones along the beach (compare with Fig. 4); 38 floats were recovered; 11, 14, 17, 18, 28, 35, 42-46 and 48 were lost

the case. At varying distances from the convergence the longshore currents turn seaward as rip currents. The rip currents merge into the coastal current outside the breakers. Where these coastal currents are moving toward the convergence, the current makes a complete circuit or an eddy, as in Figure 5 where the complete circuit of a triplane is indicated. Under conditions of high surf, lifeguards have been swept around in a circuit of this sort while trying to rescue bathers.

The currents at the canyon head are somewhat variable, but they show a distinct tendency to diverge as longshore currents flowing away from the canyon head (Fig. 3). These currents, which are a response to the angle of incidence of the waves, also turn seaward into rip currents although ordinarily the outflow is very weak, in contrast to the strong outflow from the convergence zone. To the north of La Jolla Canyon the outflow joins the outflow south of the convergence. The still water shoreward of the junction of these two currents results in a condition favorable to deposition. This condition may produce the projecting point which is so clearly shown on the map at this position (Fig. 3, station E-1).

Short period waves, normal approach--The current patterns accompanying short period waves, under nine seconds, differ considerably from those associated with longer period waves, largely

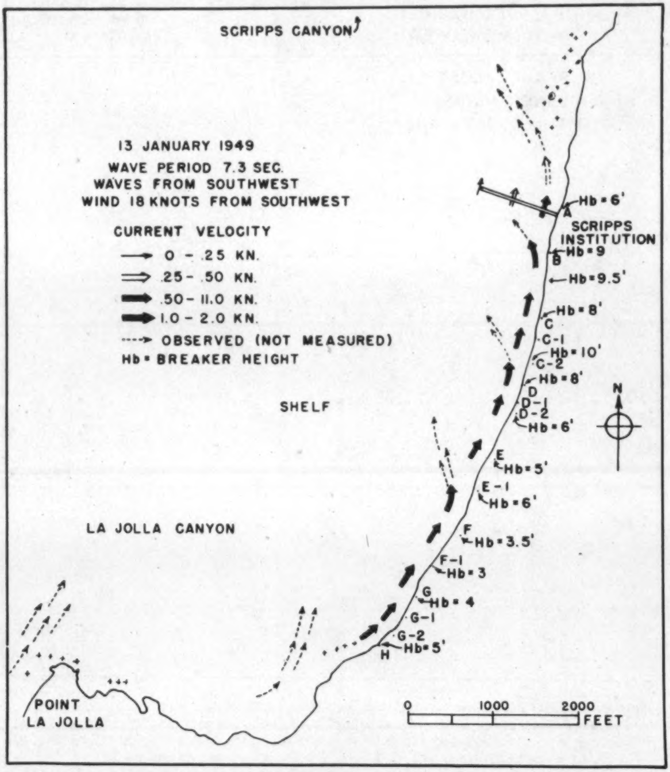
SCRIPPS CANYON
13 JANUARY 1949
WAVE PERIOD 7.3 SEC.
WAVES FROM SOUTHWEST
WIND 18 KNOTS FROM SOUTHWEST
CURRENT VELOCITY
0 - .25 KN.
.25 - .50 KN.
.50 - 11.0 KN.
1.0 - 2.0 KN.
OBSERVED (NOT MEASURED)
Hb = BREAKER HEIGHT
SHELF
LA JOLLA CANYON
POINT LA JOLLA
Hb = 6'
A
SCRIPPS INSTITUTION
Hb = 9
B
Hb = 9.5'
Hb = 8'
C
C-1
Hb = 10'
C-2
Hb = 8'
D
D-1
D-2
Hb = 6'
E
Hb = 5'
E-1
Hb = 6'
F
Hb = 3.5'
F-1
Hb = 3
G
Hb = 4
G-1
G-2
Hb = 5'
H
N
0
1000
2000
FEET

Fig. 7--Typical nearshore circulation pattern resulting from wind and short period storm waves approaching Scripps Beach from the southwest; note that all currents are moving in a northerly direction, including those at the end of Scripps Pier because the short period waves produce less wave refraction over the submarine topography. However, where the waves have essentially a normal approach (see Fig. 6), the difference between the circulation patterns accompanying long and short period waves is less striking. The pattern differs principally in that the rips are smaller and more numerous, and hence the circulation pattern is composed of a considerable number of eddy-like cells (compare Fig. 4 and 6).

Short period waves, southerly approach--During local storm conditions in which the waves and wind are from the southwest and when the waves have a short period, the circulation pattern at Scripps Beach is considerably altered (see Fig. 7). Along most of the beach the waves approach the coast diagonally from the south. Judging from the variation of breaker heights, refraction is of some importance, but the angle of wave approach is more pronounced and results in longshore currents to the north along the entire beach. The current weakens somewhat at points south of the convergence and south of the divergence, indicating some canyon effect. At several points along the shore there

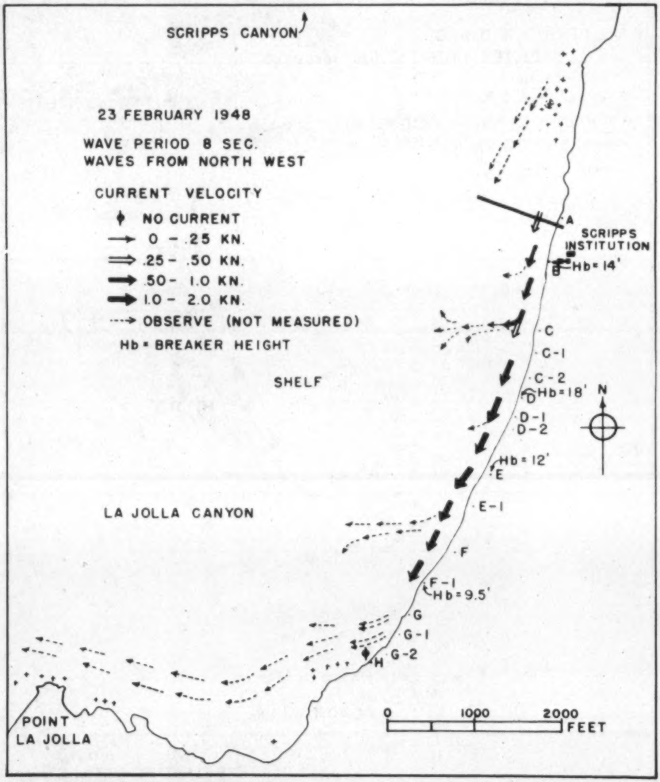
SCRIPPS CANYON
23 FEBRUARY 1948
WAVE PERIOD 8 SEC.
WAVES FROM NORTH WEST
CURRENT VELOCITY
◆ NO CURRENT
→ 0 - .25 KN.
⇒ .25 - .50 KN.
➡ .50 - 1.0 KN.
➡ 1.0 - 2.0 KN.
⇢ OBSERVE (NOT MEASURED)
Hb = BREAKER HEIGHT
SHELF
LA JOLLA CANYON
POINT LA JOLLA
A
SCRIPPS INSTITUTION
B
Hb = 14'
C
C-1
C-2
D
Hb = 18'
N
D-1
D-2
Hb = 12'
E
E-1
F
F-1
Hb = 9.5'
G
G-1
G-2
H
0
1000
2000
FEET

Fig. 8--Typical nearshore circulation pattern resulting from short period storm waves approaching Scripps Beach from the northwest; note that all currents are southerly, with a large outflow past Point La Jolla are rip currents which return some of the excess water that has built up along the shore. The nature of the flow outside the breakers has not been determined except at the pier end where it was found to be to the north.

Short period waves, northerly approach--The most violent storms of the Southern California area accompany northwest winds. During these storms relatively short-period waves build up rapidly and develop spilling breakers in water as deep as 20 to 25 ft. These waves result in a pronounced southerly longshore current along the entire length of the beach (see Fig. 8). As in the case of the

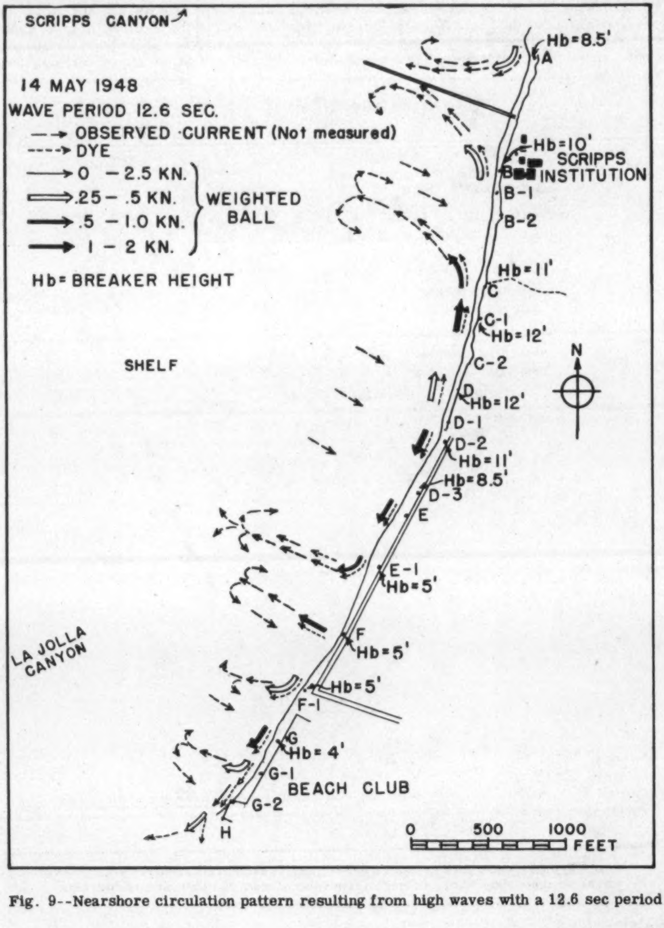
SCRIPPS CANYON
14 MAY 1948
WAVE PERIOD 12.6 SEC.
OBSERVED CURRENT (Not measured)
DYE
0 – 2.5 KN.
.25 – .5 KN.
.5 – 1.0 KN.
1 – 2 KN.
WEIGHTED BALL
Hb= BREAKER HEIGHT
Hb=8.5'
A
Hb=10'
SCRIPPS INSTITUTION
B
B-1
B-2
Hb=11'
C
C-1
Hb=12'
C-2
D
Hb=12'
D-1
D-2
Hb=11'
Hb=8.5'
D-3
E
E-1
Hb=5'
F
Hb=5'
Hb=5'
F-1
G
Hb=4'
G-1
G-2
H
BEACH CLUB
SHELF
N
LA JOLLA CANYON
0
500
1000
FEET

Fig. 9--Nearshore circulation pattern resulting from high waves with a 12.6 sec period short period waves from the southwest, a pronounced diagonal approach appears to be more important in determining the longshore current direction than the lateral gradation in breaker height due to wave refraction. The high velocities of the longshore currents associated with these waves, and the fact that their direction is continuous along the entire length of the beach, result in a large amount of sand transport.

The four patterns described above are typical of the various wave periods and directions of deep water wave approach. However, the wave height is also important in determining the circulation pattern. Very low or extremely high waves may result in a somewhat different pattern than that described for average waves of a given period and direction of approach (compare Fig. 9 with Fig. 3 and 4). Dependence of the circulation pattern upon wave height probably results from the fact that the volume of water transported shoreward by wave action is proportional to the square of the wave height [MUNK, 1949a], and that the irregular bottom topography causes a different relationship between the shoreline and breaker line for the cases of waves breaking in shoal and deep water.

Currents as a function of depth

The general circulation has been discussed above without regard to variation with depth. This procedure was justifiable since the currents from top to bottom had proved to have a similarity of pattern. However, there are gradational differences in velocity and direction (Tables 1 and 2). Since the observations do not have complete continuity through the breaker zone, it seems advisable to discuss separately the vertical gradation for the surf zone and for the zones outside the breakers. This is particularly important because different devices were used in the two zones.

Table 1--Variation of current direction with depth in the surf zone

Number of observations		
Surface and bottom in same direction	Surface alongshore, bottom diagonally offshore	Surface onshore, bottom offshore
49	17	1

Table 2--Variation of current direction with depth outside the breakers

Direction of movement	Number of observations		
	Comparison between surface and bottom	Surface and mid depth	Mid depth and bottom
Same quadrant	27	31	27
Different quadrants	5	1	1
Movement in, along,[a] or out together	22	26	19
One along,[a] the other in or out	8	5	7
One in, the other out	2	1	2
Total number of observations	32	32	28

[a] Within 15° of a line parallel to shore

Depth gradation in the surf zone--The variation of currents with depth in the surf zone is not as easily determined as it is in deeper water. Inside the breakers fluctuation in depth due to alternate advance and retreat of waves made the use of triplanes impractical since they were likely to be stranded during the retreat of large waves. Also, drift bottles were not satisfactory since they were carried shoreward by surfboard action of the waves. This action of a floating object does not necessarily indicate the direction or magnitude of the surface current, as was clearly demonstrated by the use of sea-marker dye along with drift bottles. When the powdered dye is first dropped onto the surface it moves shoreward, but as soon as it is mixed with the water the direction changes according to the circulation pattern; whereas the drift bottle is ordinarily surfboarded shoreward.

Bottom currents were measured by the weighted ball. Since the ball was slightly heavier than water, it could be expected to show a slight tendency to move downslope under the influence of gravity. However, this effect is probably minor owing to the gentle beach gradient in this area.

Figure 9 shows a number of observations along Scripps Beach in which the direction of surface movement as indicated by the dye, and the bottom movement as indicated by the ball, are compared. The center of the diffused dye patch was used as an index of the surface current. During the dye and ball observations the velocity of the ball was determined in all cases, but it was impossible, with the available personnel, to make measurements of the surface currents. However, in the abundant instances when the dye and ball were moving in the same direction, approximate comparisons could be made. It was found that the dye moved faster than the ball in virtually all such cases. An estimate can be ventured that the ball moved at about three-quarters of the velocity of the dye. On the other hand, in some cases where outward movements were observed the ball moved as fast or faster than the dye.

In approximately 73 per cent of the cases the top and bottom currents moved in essentially the same direction. Almost all of the remainder showed diagonally offshore movement at the bottom and longshore movement at the surface. Only one case was found where a surface current was moving onshore and a bottom current moving out. The reverse has not yet been observed. The comparisons seem to indicate that the bottom currents move offshore to a greater extent than the surface currents. This outward differential was found particularly in localities near rip currents. Evidently the bottom water starts the outward movement and the surface currents follow at points near the main outflow of the rip.

Depth gradation in zones outside breakers--Outside the breaker zone measurements were made near the bottom and at mid depth with triplanes and at the surface with drift bottles. The number of comparisons is not large (Table 2), but on all of the days when measurements were made the same tendency was indicated, namely, the majority of the floats moved in the same quadrant at all depths. Comparing top and bottom we found that in 84 per cent of the observations both currents moved in the same quadrant and only 16 per cent moved in different quadrants. Comparing top and middle we found the agreement even larger, 97 per cent agreeing as to quadrant. Mid and bottom currents similarly showed an agreement of quadrant in 97 per cent of the observations.

In the great majority of the observations the currents at all depths agreed in that all three moved shoreward, out, or along shore (within 15° of a line parallel to the shore). Thus in comparing top and bottom we found 69 per cent of the cases were in agreement, 25 per cent had one current moving alongshore and the other moving either in or out, and 6 per cent had shoreward movement of one current and seaward movement of the other. The top and mid depth currents had a closer accord with 81, 16, and three per cent for the same three categories, whereas the mid depth and bottom currents showed 68, 25, and seven per cent respectively.

Many of the triplane observations off areas where rips were operating showed a gradual change in direction and velocity of the current from the surface to the bottom. This spiral effect is illustrated by the triplane observations shown in Figure 3, and is thought to be the result of the superposition of the seaward flowing rip currents on the coastal current. A breakdown of a typical observation into rip current and coastal current components is shown in Figure 10. Apparently rip currents which have their origin in shoal water near the breaker zone do not extend to the bottom in the deeper water outside the breakers, whereas the coastal current which flows essentially parallel to the contours has a more nearly uniform velocity profile with depth.

At the present stage of the investigation the statistics are not sufficiently numerous to warrant conclusions as to the dominance of shoreward or seaward movement of currents at various depths. It is known that these directions vary greatly with time and place. Therefore, an insufficient number of observations can produce misleading results.

Rip currents

Rip currents are an integral part of the nearshore circulation system, being especially common in localities exposed to the open ocean. The number of rips along a beach varies widely under different conditions. As explained previously, the location of these zones of seaward moving water is in part a function of the wave period and direction (compare Fig. 4 and 6). With long period even-crested waves the rip zones are more widely spaced than for shorter-period, more irregular waves. Continued observation of a particular rip indicates that the seaward movement of water is not uniform but pulsating, and temporary complete reversals of current direction are not infrequent.

Four sets of observations over a period of five months were made to determine the nature and periodicity of the offshore and onshore currents in areas where rip currents were operating.

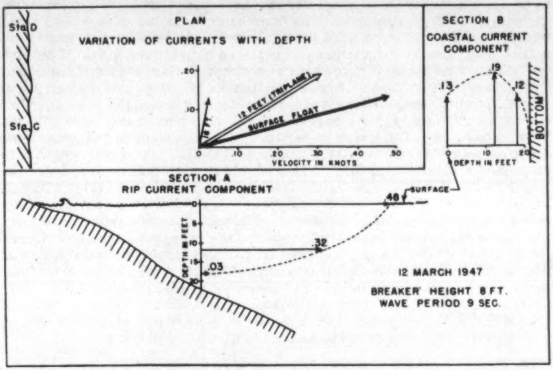
Sta D
Sta C
PLAN
VARIATION OF CURRENTS WITH DEPTH
12 FEET (TRIPLANE)
SURFACE FLOAT
18 FT.
VELOCITY IN KNOTS
SECTION B
COASTAL CURRENT COMPONENT
.13
.19
.12
BOTTOM
DEPTH IN FEET
SURFACE
SECTION A
RIP CURRENT COMPONENT
.46
.32
.03
DEPTH IN FEET
12 MARCH 1947
BREAKER HEIGHT 8 FT.
WAVE PERIOD 9 SEC.

Fig. 10--Surface float and triplane observations off station C showing the spiral effect resulting from the combination of a rip current and coastal current

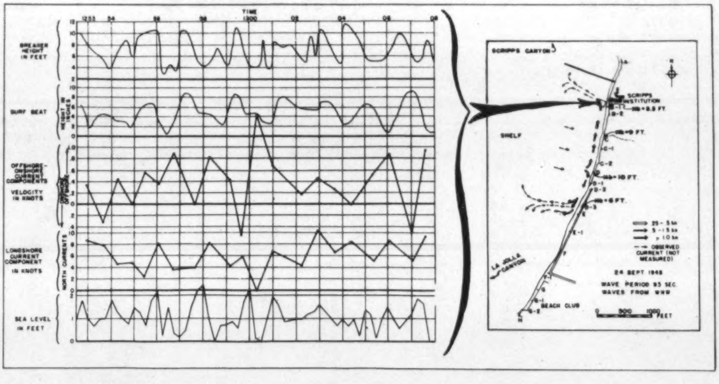

Fig. 11--Extended observations in a rip zone showing the relation between high wave groups, fluctuations in offshore current, sea level changes, and surf beat; the currents were measured with the weighted ball for 15-sec intervals; the observed velocity and direction are the vector sum of the offshore-onshore and the longshore current components; the surf beat was obtained from the tsunami recorder on the end of Scripps Pier

In these observations the current directions and velocities were obtained by using the weighted ball. Simultaneous measurements of breaker height and water level were made. The ball observations were all conducted in water ranging from 2.5 to 3.5 ft in depth, and about half way between the zone of larger breakers and the shoreline. The current observations were broken down into longshore and offshore-onshore components. These components were then compared with the breaker heights, fluctuations in sea level just shoreward of the observation points, and the wave records from the Mark III unit and the tsunami recorder.

Ocean waves are characteristically not uniform in height, a group of two or more high waves being followed by a group of small waves. The interval between two sets of high waves may be periodic or highly irregular. By introducing a time lag to allow for the wave travel time from the Mark III unit to the breaker zone, a good correlation was obtained between the Mark III record and the observed breaker height. The tsunami record showed waves with periods that coincided with the time interval between groups of high waves. These oscillations shown by the tsunami recorder appear to be caused by the variability of water transported into the surf zone, and are called "surf beat" [MUNK, 1949b]. The relationship of rip currents to (1) wave period and height, (2) the grouping of high waves, (3) surf beat, and (4) the rise in sea level, is illustrated by the observations off Station B (at Scripps Institution) on September 24, 1948 (see Fig. 11). Measurements with the weighted ball along Scripps Beach showed that there was a rip current off Station B and that the longshore current on the north side of the zone of wave convergence was to the north. At Station B the ball movement was observed for 15-sec periods and these were repeated as rapidly as possible. Analysis of the Mark III wave record and of the observed breaker heights showed that the waves had a period of 9.5 sec and a significant wave height (that is, the average of the highest one-third of the waves) of 8.5 ft. The interval between high wave groups was irregular, but the high and low groups were easily distinguished on the record. The results of the analysis of this day's records show that each group of high breakers was followed in sequence by (1) a decrease in the offshore current velocity (sometimes a complete reversal to an onshore current was observed), and (2) a rise in sea level near shore. Following this rise in sea level there was a rapid development of an offshore current which built up to a maximum during the group of low waves.

Analysis of the records of the entire observation (one hour) showed that the average period between minor fluctuations in the offshore velocity was 1.7 min, and that this period was equal to the average period of the surf beat obtained from the tsunami recorder. Major fluctuations in the offshore-onshore current were observed on an average of 7.8 min during the observations (Fig. 11; time, 13^h00^m and 13^h08^m). These major changes in velocity may be related to the variability of water transported along shore from the wave convergence zone south of Station B, or to a resonance or "beat note" between the high wave groups and the surf zone. Minor fluctuations in the offshore-onshore current which coincided in period with the high wave groups, in addition to periodic major fluctuations occurring at greater time intervals, were characteristic features of all the observations at points where rips were operating.

The pulsating character of rip currents is indicated by the triplane observations on March 12, 1947 (see Fig. 12). On that date a surface float and two triplanes were placed in the water outside the surf zone off Station C, where a rip was known to be operating. The water at this point was 20 ft deep, and the triplanes were placed at depths of nine and 13 ft respectively. During the first ten

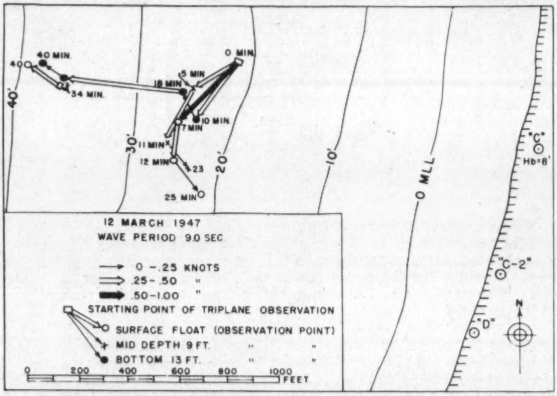

Fig. 12--Pulsating nature of rip currents indicated by surface float and triplane observations off Station C; the lower depth triplane was caught in a strong offshore current in an area previously traversed in a longshore direction by the surface float and mid depth triplane minutes of the operation the movement was toward the southwest at all three depths, the surface float and mid depth triplane leading the lower triplane by 125 ft. Following the tenth minute of the observation, the lower triplane was caught in a rip current and carried seaward at a velocity of 0.32 knots through the area previously traversed in a longshore direction by the surface float and mid depth triplane.

Conclusions

In areas where diversified submarine topography lies off relatively straight shorelines, the nearshore water circulation is ordinarily influenced to a marked degree by the wave divergence at the heads of submarine valleys and by the wave convergence over submarine ridges. At the point of wave convergence the sea surface is apparently raised a sufficient amount to develop a hydrostatic water head and results in diverging currents which flow along the beach in opposite directions away from the zone of high breakers. These longshore currents flow against the direction of approaching breakers. On the other hand a similar but less powerful outflow takes place along the shore near the point of wave divergence. The latter currents are a response to the direction of wave approach. Where the longshore currents from the wave convergences and divergences approach each other, they turn seaward as rip currents and in some cases join outside the breakers. Between the points of outflow there is a zone of quiet water which is favorable to deposition and may account for the small sand points and sand ridges which protrude on either side of many submarine canyons. Outside the breakers the rip currents are deflected by the coastal currents and move along shore to points where there is an inflowing current, thus forming a complete eddy or cell of circulation. These eddies with vertical axes are known to extend essentially from the water surface to near the bottom, the bottom velocities being less pronounced in deeper water (Fig. 10 and 12). There are ordinarily only minor differences in flow directions and velocities in the water column near shore.

The effect of wave convergence and divergence on nearshore circulation is at a maximum during times of long period waves and is almost as pronounced during times of intermediate period waves with a normal approach to the shoreline. Short period storm waves with diagonal approach definitely interfere with this submarine topographic control of currents and result in longshore currents in the direction in which the waves are approaching. Even in these cases, however, a slight influence of the submarine topography can be detected by the variation in velocity of the longshore currents. Rip currents also accompany the short period diagonally approaching storm waves. These currents are irregularly spaced and are most pronounced at the down current end of the beach.

Long continued measurements of the flow rates accompanying the rip currents have indicated that the outflowing currents are pulsating. Their flow is temporarily checked by a group of large breakers, but the rise in sea level along the shore resulting from these large breakers causes the flow to reach a maximum during periods of small breakers following the large group. Records from the tsunami recorder indicate that the high wave groups are also accompanied by long period waves of small magnitude (surf beat) that have periods similar to the period between high wave groups.

The conclusions from these studies apply only to areas with diversified submarine relief. However, since the bottom topography off most coasts is somewhat irregular, it seems likely that these relationships will apply to a limited extent in many areas where submarine contours are essentially parallel to relatively straight shorelines. The latter are known to have wave convergences apparently due to bottom projections of very small magnitude.

Acknowledgments

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HYDROSTATIC INSTABILITY IN THE OCEAN

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(Contribution from the Woods Hole Oceanographic Institution, No. 479)

Abstract--Two oceanographic sections, made by using the sea sampler, showed inversions of density at about 60 m depth. Earlier sections in the same neighborhood, the edge of the continental shelf, reveal this same feature. The establishment and maintenance of this instability appears to be associated with tidal currents.

On August 4 and August 6, 1948, two sections were made from the U. S. Fish and Wildlife Service vessel Albatross III normal to the edge of the continental shelf, south of Cape Cod, as shown in Figure 1. The primary purpose of these sections was to test the new pressure-operated sea sampler described by SPILHAUS and MILLER [1948].

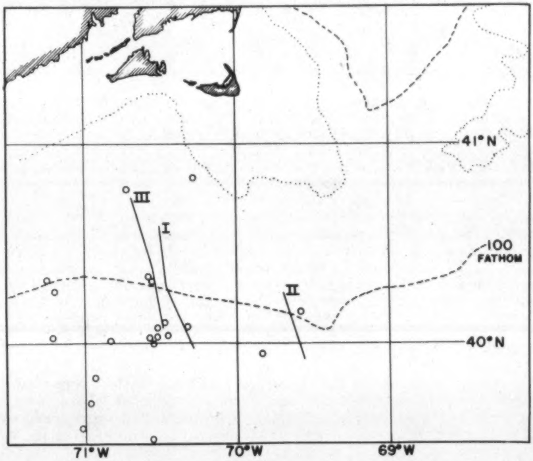

Fig. 1--Chart showing positions of sections and stations where instability has been observed; Section I taken Aug. 4, 1948; Section II taken Aug. 6, 1948; Section III taken by Bigelow, June, 1933; ○ Nansen bottle stations

Observation of inversions of density--During these two sections, the vessel was moving at full speed, approximately nine knots. Soundings providing the temperature-depth trace and twelve samples each were made about every 20 min. Salinity and oxygen values were determined on board as the soundings were obtained. From the temperature and salinity readings at the same points, density (more precisely σ_t, but the distinction need not be made at the shallow depths) was computed, and the two sections are shown in Figure 2. The first thing that was noted was that in layers well below the surface of the ocean there were places where density decreased with increasing depth.

Investigation of possible errors which might account for density inversions--To determine

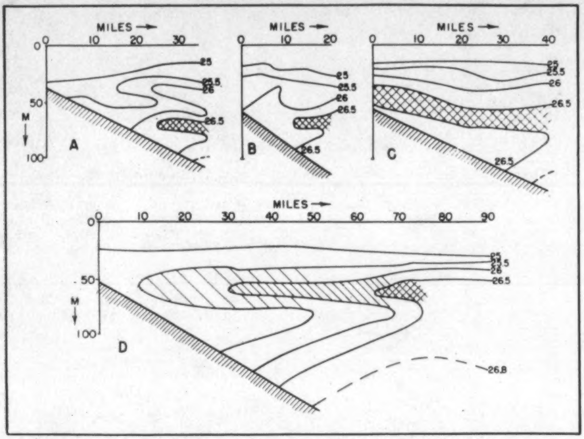

Fig. 2--Distribution of density (σ_t) on the continental slope; (A) Section I, 12 soundings; (B) Section II, 7 soundings; (C) Bigelow Section, 3 stations; (D) Atlantis Cruise 80, 10 stations

whether the inversions were due to either mechanical, chemical, or computational errors, the following possible sources of error were investigated:

(1) Mechanical failure of the sea sampler, if it resulted in taking the water sample at a depth different from that at which the temperature was recorded would result in combining a salinity and temperature which do not refer to the same water parcel. This could easily account for the inversions of density. However, the sea sampler is so constructed that the single pressure element operates the thermograph slide and the triggering device as an integral unit. Even though the sample might be taken at the wrong depth due to friction or some other cause the temperature would be recorded at the same incorrect depth. It is impossible for samples to be taken in the wrong order. Failure to take the sample at the prescribed point results in breakage of the triggering pin. Therefore, mechanical failure cannot account for these inversions.

(2) The bathythermograph part of the sea sampler makes a trace of temperature against depth on the slide on both the instrument's descent and ascent. In the upper layers, because at nine knots there is some considerable geographical separation of the point of immersion and emergence, the two traces may differ by a certain amount. Below 100 ft, however, the two traces are almost always indistinguishable. Recomputations of σ_t values were made, using extremes of temperature shown by the two traces. Such recomputation did not eliminate the strong inversions of density in the lower levels.

(3) As salinities were titrated rapidly on board, it was thought that here, possibly, was a source of error. Approximately one-half of the samples were rechecked on shore. The greatest difference between the check and the original titration was found to be 0.06 $^0/oo$, the average difference 0.03 $^0/oo$. The values of σ_t were recomputed, allowing a possible error of salinity of 0.10 $^0/oo$, and even with this the inversions of density were still present.

Previous observations--The authors' observations of inversions of density were regarded with considerable skepticism at first, because it was thought that they might be the result of improper functioning of a new type of instrument. However, this has been shown above to be impossible. In order to further substantiate the observations a search was made of all the soundings in the same general region, between 39°30 and 40°30 N and 69° and 71°30 W. A considerable number of soundings made with the Nansen bottle technique showed sub-surface inversions even after eliminating several

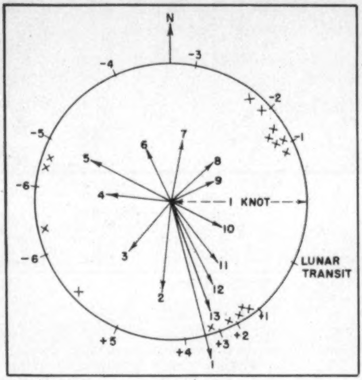

Fig. 3--Time of occurrences of instability (×) in relation to time of lunar transit and tidal currents

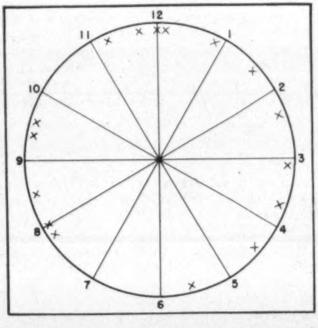

Fig. 4--Time of occurrences of instability (×) in relation to time of solar transit (local time)

which were in error. The positions of these soundings are also plotted on Figure 1. It has been the practice hitherto to disregard as erroneous any observation in which density decreased downwards. In Figure 2 are shown sections (made previously with Nansen bottles) which exhibit the same feature [unpublished data from Stations 3116-3126 on Atlantis Cruise 80, 1938; and BIGELOW, 1933]. All four sections show a tongue of more dense water ($\sigma_t = 26.7$) overlying lighter water ($\sigma_t = 26.2$) at a depth of about 200 ft.

Cause of instability and its relation to tidal currents--The region under investigation lies in the area where there is the principal outflow from the Gulf of Maine, Figure 1. Here there is considerable variation of the outflow velocity due to tidal currents, as shown in Figure 3. It was thought that this instability might be set up by the tidal "pumping" of water from the Gulf of Maine. If the inversions are due to tidal accelerations, then their occurrences should show a semi-diurnal lunar period. The time of lunar transit is given for each sounding. Figure 3 shows the time of occurrence of the inversions expressed in hours before or after the time of lunar transit on the particular day. Measurements of the currents of this area in relation to the time of lunar transit are also shown. It is apparent, upon inspection of Figure 3, that the instability is observed when the component of the acceleration of the current in the direction of the hydrographic sections (12 cases) is directed outwards toward deeper water. Only four cases occur when the acceleration of the current is in the opposite direction. Computation of the possibility that this distribution was fortuitous reveals an extremely small probability that the distribution was really uniform. On the other hand, if these observations are plotted in relation to the Sun's transit, the distribution, Figure 4, is obtained. Applying the same computation, the probability that this is a uniform distribution is very high. From this result one must conclude that the tidal accelerations are connected with the occurrences of inversions of density in this region.

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PULSATIONAL TRANSPORT OF SAND BY SHORE AGENTS

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Abstract--The building of sand spits at tidal inlets represents deposition of shore drift, and interrupts the otherwise relatively continuous migration of sand along the shore. Under normal circumstances the spits are beheaded by new inlets when they attain unstable length, detaching a body of sand which merges with the beach and continues its downbeach movement beyond the inlet. A similar phenomenon occurs in tideless bodies of water, and has been observed at Waukegan, Illinois. In this instance an under water spit is beheaded by reverse wave-generated shore currents; and the beheaded portion deteriorates into a formless veneer of sand on the lake bottom, ultimately rejoining and adding to the downbeach shore drift.

Introduction--The movement of sand along a straight beach relatively remote from inlets or stream mouths manifests itself by accretion on the updrift side of groins and other structures. The direction of the drift is a function of the prevailing currents, which in the general case arise from waves striking the shore at an angle. Where the current-generating waves are prevailingly from one direction, the sand moves with the sweep of the waves; where waves approach from several directions, the net movement is a statistical balance of the alternating current directions.

Along the western shore of Lake Michigan in Illinois and southern Wisconsin, the waves approach from the northeast about two-thirds of the time that waves are running, and about one-third from the southeast. Both the average period and average height of the northeast waves are greater than for the southeast waves. Southward flowing wave-generated currents prevail, and the net movement of shore drift is southward. Seasonally, however, the direction of movement may be reversed, and during the summer the prevailing southeast waves commonly are accompanied by sand accumulation along the south sides of groins and piers. The ensuing fall and early spring storms usually offset the effects of this minor northward drift.

Observations along straight, uninterrupted beaches show that over a period of years the net amount of shore drift past any point is fairly uniform, and for any given decade it may reasonably be expressed as an average amount per year. Over longer periods the amount of drift may change significantly, especially if shore protection is undertaken along earlier sites of erosion upbeach, if flood control reservoirs are built along main source streams or if harbor jetties or similar structures are built upbeach. Along the western shore of Lake Michigan in Milwaukee County, Wisconsin, it is estimated that the amount of shore drift has been significantly reduced during the past 50 years, largely as a result of shore protection structures, such as sea walls and the like.

Measurements of the amount of sand trapped by harbor structures, in comparison with estimates of the load based upon rates of erosion of known source areas, lead to the conclusion that even long structures do not stop all the drift. Studies along the western shore of Lake Michigan show that long harbor jetties arrest some 50 to 80 per cent of the shore drift, and that immediately south of the jetty the drift is much impoverished. A few miles farther south, however, the drift becomes richer again, commonly at a rate more rapid than that caused by normal additions to the load by erosion along the intervening stretch. Moreover, there is some evidence that movement past the structures is intermittent rather than continuous.

At Waukegan, Illinois, and also at Wilmette, Illinois, a fairly rich shore drift is partially stopped by structures, with the development of a lean drift area along the shore immediately downbeach. Farther downbeach the drift becomes richer again, suggesting movement of sand around the end of the structure, in depths of 12 to 18 ft, and a return of the drift toward the shore beyond the "shadow zone" created by the obstacle. Preliminary attempts to locate definite underwater bars in the presumed path of movement have been unavailing, although irregular temporary bars may be observed at times southeast of the structures. Apparently the migrating sand is in the form of a relatively thin veneer which moves along the bottom as a formless sheet, in the general direction set by dominant wave action. Evidence presented in this paper demonstrates that intermittent transport occurs past the structures, much in the manner of pulsational transport past tidal inlets on ocean beaches, but caused by a different mechanism.

Movement of sand past tidal inlets--Numerous observations made along the Atlantic Coast demonstrate that sand movement past tidal inlets is pulsational, in the sense that masses of sand are translated downbeach by the opening of new inlets to the windward of earlier inlets. The most definitive statement of the case is given by the BEACH EROSION BOARD [1933]. Two general situations are discussed, involving crescentic bars and growing sand spits.

The development of crescent-shaped bars in front of inlets is described as arising in part from the pattern of current flow in the vicinity of tidal inlets during flood and ebb tide. During ebb, the normal littoral current is deflected seaward, and may deposit part of its load as a crescentic bar. The point at which the main current passes through the bar shifts with time, and if the shift is in an upbeach direction a mass of sand in the bar is transferred from the upbeach to the downbeach side of the inlet and continues its movement downbeach.

The second situation is concerned with the growth of a sand spit at an inlet. Under conditions of heavy drift, sand is deposited in deeper water at the upbeach side of the inlet, and the inlet itself is forced in a downbeach direction by scour. Under proper conditions the spit in the upbeach end may become much elongated, deflecting the inlet along a channel parallel to the spit, until a very asymmetrical inlet is developed. The resulting condition is unstable, inasmuch as new inlets may be developed in the lengthening barrier during storms or high tides. When this occurs, a mass of sand is translated past the inlet and resumes its normal downbeach migration.

As a result of these processes, sand movement past inlets is intermittent or pulsational instead of relatively uniform as along straight beaches remote from inlets or other obstacles. The discontinuous effect is heightened by the occurrence of new inlets downbeach with respect to a given point, which in effect translates a body of sand upbeach with respect to a point beyond the new inlet, and so introduces additional obstacles for the sand to pass.

The effect of pulsational transport is felt most strongly a short distance downbeach of a new inlet. The abrupt cessation of the normal drift may result in the development of erosional scars, as the cleared current picks up sand in its progress past the impoverished area. Some distance below the inlet steady state conditions may again be achieved, with a much lesser effect on the beach remote from the inlet.

An interesting instance of migration of an erosional scar was observed southeast of Santa Barbara, California, in 1942. The construction of the yacht harbor at Santa Barbara resulted in stoppage of normal drift to the southeast, and developed an erosional scar downbeach. Later, when sand was pumped across the harbor, the new supply re-established the beach in part, and normal southeast migration resulted in the movement of the erosional scar along the shore, followed by refill phenomena as the effects of the new supply repaired the earlier damage.

Along the western shore of Lake Michigan similar erosional scars occur at times, and seem to migrate downbeach. An instance was observed at Milwaukee, Wisconsin, in 1944, but whether it arose as a result of some pulsational movement of drift upbeach is not known. At Waukegan, Illinois, definite evidence of pulsational movement past the harbor jetty is available, and the mechanism of the pulsational transfer can be shown to be related to opposing wave-induced currents, which alternately build and behead an underwater spit.

Movement of sand past Waukegan harbor--A series of surveys was made at Waukegan by the United States Corps of Engineers over the period 1933 to 1948, to check channel dredging operations. Soundings taken at periodic intervals showed various stages of a process which involved the growth of a rounded underwater spit to the south of the main harbor jetty; this spit become detached at its northern end and moved as an isolated bar across the deeper water opposite the channel entrance. As this bar was followed southward, its identity became lost, and presumably it deteriorated into a thin veneer of sand which migrated across the bottom to merge with the nearshore drift farther south.

From a study of the successive surveys, plus other available data, it was possible to arrange the survey data into a pulsational cycle, even though each stage was not represented in strict time-sequence in the surveys. Figure 1 shows the setting of Waukegan harbor, and the slightly generalized depth contours associated with the initial stages of pulsational movement of the sand. The critical depths lie between 18 and 24 ft, which are the main contours shown, although other depths are included for completeness. The 22-ft depth is indicated as a dashed line, inasmuch as it represents the depth of dredging. In Figure 1 the somewhat rectangular form of the dredged channel may be discerned. At this initial stage the 18-ft contour on the north swings just beyond the north jetty, and joins with the shallower part of the channel. South of the south jetty the 18-ft line extends

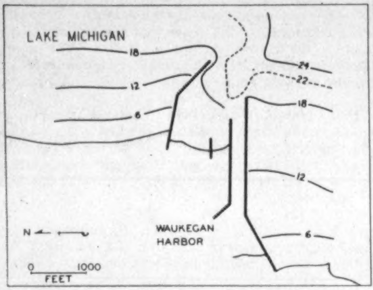
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Fig. 1--Initial stage of underwater spit-building process, immediately after channel dredging

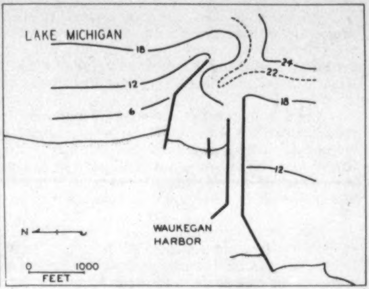
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Fig. 2--Intermediate stage during growth of underwater spit

approximately parallel to the shore from the jetty edge.

Figure 2 shows a later stage, in which the underwater spit has grown in a southeasterly direction until it extends to the order of 1000 ft beyond the end of the north jetty. The 12-ft line has moved to the end of the jetty, and the 22-ft channel has been narrowed and crowded southward. The depth relations south of the south jetty remain much as they were.

In a later part of the growth stage, a small nick is observed in the depth lines adjacent to the end of the north jetty, indicating some constriction of the neck of the spit. With time this nick is enlarged until in the third stage the end of the spit is isolated as a shallow mound, with a relatively deep channel at the edge of the north jetty, as shown in Figure 3. This is the beheading stage, and establishes the pulse of sand as an isolated shallow area surrounded by deeper water. Apparently there is some adjustment also of the southern extension of the 18-ft depth, in which incomplete evidence suggests a landward swing of the line as shown in Figure 3, indicating some deepening of the water.

The last stage in the process is shown in Figure 4, which illustrates the close of one cycle and the incipient stages of the next. The isolated mound of underwater sand has apparently deteriorated into a formless sheet, which suggests its presence by the adjustment of the depth curves south of the south jetty. The sheet of sand follows a path toward shore farther south, where an increase

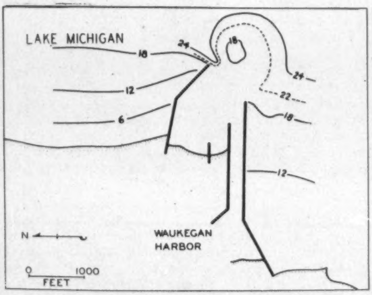
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Fig. 3--Beheading of underwater spit, and development of isolated mound of sand

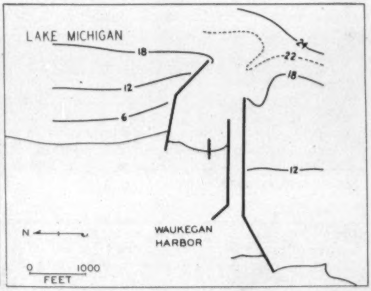
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Fig. 4--Final stage of beheading cycle, and initiation of conditions for succeeding cycle

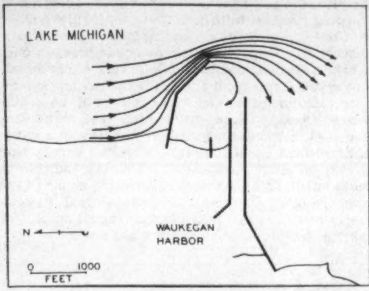

Fig. 5--Streamlines of southward-flowing wave-induced currents

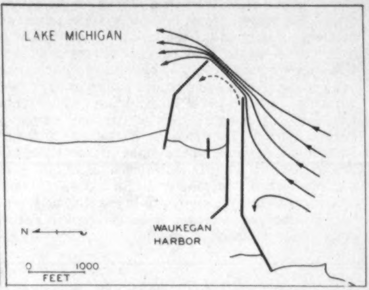

Fig. 6--Streamlines of northward-flowing wave-induced reverse currents

occurs in the shore drift beyond the amount which can be explained by erosion of the intervening stretch. Thus it seems safe to conclude that the pulsational migration carries sand past the harbor jetties, where it again becomes part of the nearshore drift. No evidence is available of the amount which may be lost to deep water in the process. The mechanism of the pulsational movement is found in the wave-induced currents adjacent to the harbor. Fortunately, observations were available which establish the surface streamlines of these currents, although the magnitude of the wave action and currents near the bottom is not known.

Figure 5 shows the dominant southward-flowing current deflected around the north jetty, and extending as a widening stream to the south, with a tendency to move back toward the shore. Some harbor eddies are undoubtedly associated with this pattern of flow, but they have not been studied in detail. It is this southward-flowing current that is responsible for the growth of the underwater spit. The normal shore drift is partially deflected around the end of the north breakwater, and is deposited in the deeper water at the end of the growing spit. The decrease in current velocity just beyond the end of the structure is shown in part by the streamlines; and the effect of increasing depth is probably even more prominent on the velocity of the bottom currents which move the sand.

The continuity of the southward-flowing current is interrupted at times by a reverse current developed by southeast waves, as shown in Figure 6. Usually the reverse current is very weak compared to the dominant current, but at times when waves run from the southeast for several days, the reverse current may become fairly strong. Floats used in mapping the current showed that at such times the reverse current moved as a narrow stream (about 150 ft wide) from the end of the south jetty almost straight across to the end of the north jetty. An eddy is shown in the harbor, but this was not studied.

The sequence of events involved in the pulsational transport is seen to include a gradual growth of the underwater spit under the influence of dominant southward currents, with cessation of growth while relatively weak reverse currents flow over and around the relatively short spit. As the spit elongates, the tendency is for the reverse currents to flow over the bar, cutting a shallow channel at times when they are strong enough to do so. In time, as the spit elongates to a statistical limit of stability, a prolonged interval of moderate, or a shorter interval of very large, southeast waves creates bottom conditions strong enough to scour a deep channel across the bar, thereby beheading it and isolating its distal end. The isolated mound of sand, cut off from its normal supply, is subject to movement when the southward-flowing currents again dominate. Apparently the irregular shape of the isolated bar is not stable enough to maintain its form, and it degenerates into a formless sheet which moves across the bottom along the general path established by the southward current pattern. The isolated bar has an average volume of 5000 to 10,000 cu yd.

Data are scant on the interval of time required for the pulsational cycle. Daily wave data are available for Evanston, Illinois, about 22 mi south of Waukegan, for the past three years. These data were analyzed to determine the number of times per year that intervals of continuous waves occur for four days or more. It was found that continuous duration of waves from the northeast and east for four or more days occur about 19 times a year, whereas similar durations for southeast waves occur only five times a year on the average. For the northeast and east waves, about 12 of the 19 intervals have at least one day's waves exceeding two feet in height, whereas for the southeast waves only one of the five per year has at least one day's waves exceeding two feet in height. These data suggest that reverse currents strong enough to behead the spit may occur between one and five times a year. On the other hand, there seem to be sufficient continuous intervals of northeast and east waves to assure adequate growth of the underwater spit during times between strong reverse currents. As a point of information, waves from the east constitute some 15 per cent of the northeast and east category. As an independent means of estimating the pulsational interval, some data are available on the load passing the harbor jetty at Waukegan. From the available surveys, it appears that the underwater spit seldom attains a length of more than about 1500 ft; and from a survey showing this greatest length, the volume of sand in the spit may be roughly estimated. The data indicate that sufficient sand is deposited to form a spit of unstable length on an average of about 18 months each. Intermittent migration due to beheading may occur more often than this 18-month interval, however, because the volume found to be isolated in Figure 4 is less than that found in the longest spits. Based on the volume isolated, the supply is adequate to permit beheading once every eight months.

The difference between the volume beheaded and the volume of the unstable spit may be visualized as the portion of the spit eroded and moved northward during the beheading process; but when the predominant southward-flowing current is again established, this eroded material is returned to contribute immediately to the formation of a new underwater spit. The speed with which the process may proceed is demonstrated by soundings taken prior to and subsequent to a two-day storm in 1929, during which an amount of material sufficient to form an unstable spit was deposited. The wave data show that southeast wave action sufficient to establish beheading currents may occur from one to five times a year, which is an adequate frequency to meet the conditions of supply for isolation of a portion of the spit. The conclusion is drawn that the period between successive beheadings may vary from six to 18 months; and probably is about eight months on the average.

Concluding remarks--The problem of pulsational or intermittent transport of sand by shore agents is of interest both in academic studies of shore drift along tideless bodies of water, and in applied aspects of beach engineering. From the latter point of view it is evident that if the pulsational process occurs as stated, with a "shadow zone" downbeach of the obstacle, it becomes important to understand more fully the path followed by the moving sand after the spit is beheaded, so that the rate of increase of shore drift downbeach may be better evaluated. Moreover, it becomes apparent that groin systems in the shadow zone will have relatively little efficiency because of the impoverished drift; and hence the extent of the shadow zone becomes important. Lay suggestions of offshore breakwaters so oriented as to direct the sand back to shore may not be feasible, but the possibility that some factors in the process or along the path may be subject to control raises interesting problems. The effect of intermittent transport on entrance conditions in harbor channels is also worthy of future study. There is a possibility that critical entrance conditions immediately after beheading may be alleviated somewhat by further migration of the isolated bar; and its rate of movement accordingly becomes a matter of some interest.

If pulsational transport is the rule along both lake and ocean beaches that are interrupted by inlets, structures, or other obstacles to continuous transportation, consideration of the consequences of such movement becomes significant in terms of periodic increase and decrease of drift as a function of distance downbeach of the obstacle. A better understanding of the geological implications of shore processes may be gained, and a better theoretical basis had for beach engineering installations, such as groins, seawalls, and the like.

Acknowledgments--The writers are indebted to W. P. Trower, District Engineer, of the Chicago District, Corps of Engineers, Department of the Army, for making available soundings and other data on which this study is based. J. V. Hall, Jr., and H. A. Ward of the Beach Erosion Board, Office of the Chief of Engineers, Washington, D. C., kindly furnished additional information and maps which greatly facilitated the study. M. A. Mason of the Beach Erosion Board made helpful suggestions in the preparation of the manuscript.

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DISTRIBUTION OF SOUND VELOCITY IN A SECTION OF THE EASTERN NORTH PACIFIC

Ernest R. Anderson

Abstract--Vertical and horizontal distribution of sound velocity have been obtained for the eastern North Pacific area from an analysis of the temperature and salinity data taken at 23 hydrographic stations during Cruise I of the USS Serrano (ATF 112) in November, 1948. A method for extending the vertical sound velocity curves to the ocean bottom is suggested. Certain specific characteristics of the sound velocity distribution, such as the depth and velocity at the top, axis, and base of the sound channel are described. The relation of the various features of the area is discussed.

Application of this information to the use of the deep sound channel in air-sea rescue (Sofar) is discussed. For several test explosions in the eastern North Pacific the position of the explosion was computed from the arrival times of the sound waves at each shore station. The computed positions were within a few miles of the navigated position of the ship which dropped the bombs.

Introduction--In late 1943, Maurice Ewing [EWING and others, 1946, p. 930] proposed that the deep sound channel in the ocean be used to transmit low-frequency sound for very great distances, that is, several thousand miles. Additional research [EWING and WORZEL, 1948] into the properties of the sound channel indicated that it would be feasible to utilize a network of three or more receiving hydrophones in locating given sound sources for air-sea rescue work.

Such hydrophone stations have now been established in the eastern North Pacific, and the network is being systematically evaluated. The first of several cruises, planned for this purpose, has been completed and an analysis is being made of the data obtained. These include physical oceanographic data, data on the characteristics of the sound channel in the eastern North Pacific, and checks on the accuracy of location by the Sofar method.

Definitions--Terms that will be used in the following discussion in describing the sound channel are defined below (see Fig. 1):

(1) The region of minimum velocity with higher velocity above and below is known as the sound channel.

(2) The top of the sound channel in this region occurs at a depth, near the surface, where the sound velocity reaches a maximum. In Figure 1 the top of the sound channel is at approximately 50 m.

(3) The sound-channel axis is that depth at which the sound velocity reaches a minimum. In Figure 1 this occurs at 500 m.

(4) The bottom of the sound channel is the depth at which the sound velocity again attains a value equal to that at the top of the sound channel. In Figure 1 this occurs at 2500 m.

(5) The width of the sound channel is the difference in depth between the bottom and top of the sound channel. In Figure 1 the width of the channel is 2450 m.

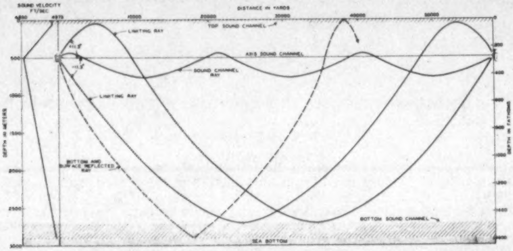
When sound travels in a medium in which the velocity changes with depth, the sound rays are refracted according to Snell's Law. Some of the rays which are of interest in considering long-range sound transmission are defined as follows:

(6) The limiting ray is the sound ray tangent to the top and bottom of the sound channel. The angle this ray makes with the horizontal is the angle of the limiting ray. In Figure 1 the limiting ray has an angle of ±11.3°.

(7) Some rays leaving the sound source at angles less than the limiting ray will cross and recross the sound channel axis indefinitely until the sound energy is absorbed, scattered, or intercepted by some obstacle. These are known as the sound channel rays.

(8) Sound rays leaving the sound source at angles greater than the limiting ray will be reflected by either the bottom or surface or both. These are reflected rays.

It has been assumed that the angle between the limiting rays (or the difference in maximum and minimum sound velocity) is indicative of the strength of the sound channel, the greater the angle the stronger the channel.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10000
20000
30000
40000
50000
0
LIMITING RAY
TOP SOUND CHANNEL
+11.5°
AXIS SOUND CHANNEL
-11.5°
SOUND CHANNEL RAY
LIMITING RAY
BOTTOM AND SURFACE REFLECTED RAY
BOTTOM SOUND CHANNEL
SEA BOTTOM
DEPTH IN METERS
500
1000
1500
2000
2500
3000
DEPTH IN FATHOMS
200
400
600
800
1000
1200
1400
1600

Fig. 1--Model sound channel showing typical sound-ray paths and defining various terms used in discussing the distribution of sound velocity in the ocean

Computation of limiting rays--A formula for calculating the limiting ray for the deep sound channel, based upon elementary geometrical considerations of sound refraction in sea water, will now be developed. In this development it is assumed that Snell's Law of Refraction is valid.

In Figure 1 let θ be the angle of the limiting ray at the sound channel axis, θ_o be the angle of the ray at the top of the sound channel, c be the velocity of sound at the sound channel axis, and c_o the velocity of sound at the top of the sound channel. Then by Snell's Law

$$(\cos \theta)/c = (\cos \theta_o)/c_o \quad \ldots\ldots\ldots\ldots \quad (1)$$

For small angles the sine of the angle is approximately equal to the angle expressed in radians, hence,

$$\cos \theta = \sqrt{1 - \theta^2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

and

$$\sqrt{1 - \theta^2} = c\sqrt{1 - \theta_o^2}/c_o \quad \text{or} \quad 1 - \theta^2 = (1 - \theta_o)^2\,(1 + \Delta c/c_o)^2 \quad \ldots\ldots\ldots\ldots \quad (3)$$

where $\Delta c = c - c_o$. Since $\Delta c/c_o$ is a small quantity

$$\theta^2 = \theta_o^2 - 2\Delta c/c_o \quad \ldots\ldots\ldots\ldots \quad (4)$$

In the case of the limiting ray $\theta_o = 0$, and the formula for the limiting ray becomes

$$\theta^2 = -\,2\Delta c/c_o \quad \ldots\ldots\ldots\ldots \quad (5)$$

It is seen that the limiting ray is a function of the velocity difference between the velocity at the sound channel axis and the actual velocity at the top of the channel. A negligible error is introduced if it is assumed that c_o is equal to 4900 ft/sec. This has been done in preparing a graph of the limiting ray as a function of velocity difference only. This graph has been used in computing the limiting ray.

Vertical and horizontal distribution of sound velocity--Figure 2 shows the route, hydrographic stations, and bathythermograph stations, taken from November 10 to November 23, 1948, by the USS Serrano. Hydrographic stations, whose locations are shown by the black dots, were made at 23 locations. At each hydrographic station water samples and temperatures at 17 depths from the surface to 1200 m were taken by means of Nansen bottles and deep-sea reversing thermometers. In order to obtain detailed observations in and near the sound-channel axis the water bottles were spaced at 50-m intervals. Since two casts were used, the top of the deep cast overlapped the shallow cast by 50 m. In addition, bathythermograms were made to a depth of 137 m at all hydrographic stations, and at those additional locations indicated by a cross in Figure 2.

The final temperature data were obtained by utilizing standard methods for reducing the recorded temperatures to in situ temperatures. These temperatures are accurate to ±0.02°C. The

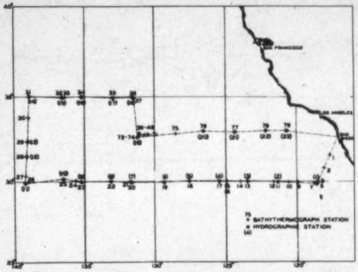


Fig. 2--Location of hydrographic and bathythermograph stations made on *Serrano* Cruise I

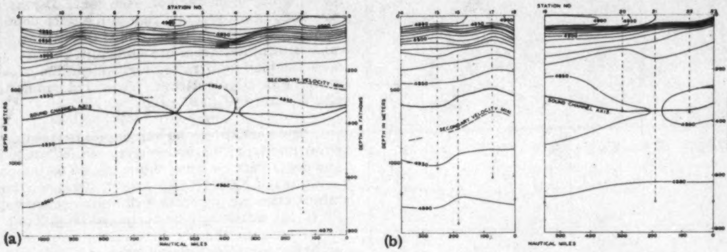
depths of the observed temperatures were calculated by using four unprotected deep-sea reversing thermometers on each cast. Depths are accurate to 0.5 per cent of the wire depth. Using KNUDSEN'S [1901] tables the salinity was determined from the chlorinity, which was obtained by titrating a given sample of sea water with silver nitrate. These determinations are accurate to ±0.04 o/oo.

The vertical sound velocity distribution was computed from the above temperature, salinity, and depth data by using tables based on the computations of KUWAHARA [1939]. By use of these tables absolute accuracy with which sound velocity in sea water may be computed is ±0.2 per cent. With the temperature measurements accurate to ±0.02°C and salinity to ±0.04 o/oo, the relative accuracy of the computed velocities is approximately ±0.7 ft/sec.

Since data at each hydrographic station were obtained only to a depth of 1200 m, it was necessary to devise a means of extrapolating the sound velocity curve to the ocean bottom in order that a complete picture of the sound velocity distribution could be obtained. It is reasonable to assume that below some depth in a given water mass the sound velocity would become almost a function of depth only. Therefore, if two hydrographic stations were made at different locations the sound velocity at these two stations would be the same below this depth. This reasoning is based on the fact that at great depths, within the same water mass, the temperature and salinity remain essentially constant throughout the year. This indicated a possible method for extrapolating the observed sound velocity curves to the ocean bottom. *Carnegie* stations 132, 133, and 135 [FLEMING and others, 1945] and *Bushnell* station 309 [SVERDRUP and Staff, 1943] had previously been made in this area. At these stations samples were taken from the surface to very near the bottom. The sound velocity curves for each station were computed and it was found that the sound velocity at 1200 m agreed closely with that of the *Serrano* stations at 1200 m. As a result, the data of the *Carnegie* or *Bushnell* station which, at 1200 m, agreed the best with the *Serrano* 1200-m sound velocity, were used to extrapolate the sound curves to the ocean bottom.

Figure 3 shows the resulting vertical cross section of the sound velocity distribution from the surface to 1200 m. The isopleths are entered for a sound velocity interval of ten ft/sec. The dotted line indicates the depth of the major minimum sound velocity, or the sound-channel axis, while the broken line indicates the depth of a secondary sound velocity minimum. Figure 3a, which is an east-west 1100-mile section taken along latitude 30° N, shows a remarkable constancy in the depth of the axis. The depth varies from 600 to 700 m, being slightly deeper to the west. Shallower secondary velocity minima are present at Stations 1, 2, and 7. To the right in Figure 3b is an east-west section along 33° N. Again there is a constancy of depth of the sound-channel axis, varying from 550 to 650 m. To the left of Figure 3b is another east-west section taken along 35° N. The same constancy of depth is shown, varying in this case from 500 to 600 m. Secondary minima are present at Stations 14, 16, and 17. Figure 3c presents two north-south sections, the right hand section being taken along longitude 131° W, and the other along 139° W. Both sections show a decrease in depth from south to north of the sound-channel axis, with the western section decreasing from 700 to 600 m and the eastern section from 650 to 550 m. In summary, Figures 3a, b, and c reveal that the sound-channel axis increases slightly in depth from east to west and shoals from south to north. In addition, it may be noted that between 1200 and 1300 m the sound velocity is nearly constant, having a value of 4860 ft/sec or 2878 mi/hr.

Figure 4 shows the details of the sound velocity distribution from the surface to 100 m. These figures have been prepared for the same sections as those shown in Figure 3. The dashed-dotted line indicates the top of the sound channel. Figure 4a shows that the top of the channel has a wave-like pattern, generally increasing in depth from east to west. Likewise the sound velocity at any given depth shows a similar pattern. Figure 4b reveals the same features. The north-south sections, Figure 4c, suggest a general decrease in depth of the top of the channel, as well as in the sound velocity, at any given depth. At all stations there was a positive sound velocity gradient above the top of the sound channel. This is probably caused by seasonal mixing of surface layers. In summary, the depth of the top of the sound channel and the distribution in velocity at any given depth



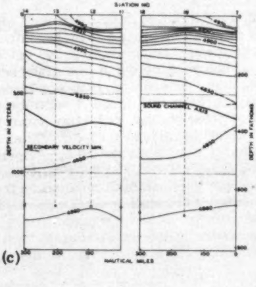


Fig. 3--Vertical cross-section of the distribution of sound velocity (ft/sec) from the surface to 1200 m (a) east-west, stations 1-11; (b) east-west, stations 18-14 and 23-19; (c) north-south, stations 11-14 and 7-18

show an increase toward the west and a decrease toward the north, accompanied by a wave-like configuration.

Figure 5 represents the horizontal distribution of sound velocity at the sound-channel axis. Two features are outstanding: (1) the eddy-like appearance of the distribution with alternating tongues of high and low sound velocities, and (2) the small velocity gradients along this surface with a difference of only 10.1 ft/sec or 6.0 mi/hr between the maximum and minimum observed velocity. For practical purposes, in this area, an average velocity of 4850 ft/sec for the axis sound velocity is used in calculating the location of any given sound source.

The velocity at the top of the sound channel and at the bottom of the sound channel are the same by definition. The horizontal distribution at these depths is presented in Figure 6. The distribution shows an increase in velocity towards the west and south. As can be seen, the velocity gradient at these levels is considerably greater than at the sound-channel axis.

The depth of the bottom of the sound-channel has been obtained in the manner already described. Figure 7 presents the depth of this surface. Again, as in the case of other features of the sound velocity distribution, the depth increases from east to west and north to south, varying from 2800 to 3800 m, with the surface being slightly undulatory. At no station was the bottom of the sound channel limited by the ocean floor.

Figure 8 shows the width of the channel. It varies from 2800 m near the California coast to 3700 m at longitude 139° W. A measure of the strength or development of the sound channel may be obtained from the angle of the limiting ray, which in turn, is a function of the difference in velocity at the top and axis of the channel. Figure 9 presents the velocity difference at the top and axis of the channel. This increases from 80 ft/sec at the east to 145 ft/sec at the west. This corresponds to an increase in the limiting ray angle from 11° to 14°. The value of the limiting ray angle to the nearest whole degree is also shown on the figure.

The limiting ray angle varies from near zero degrees in the North Pacific during the winter to 17° in equatorial waters. Using this as a criterion of channel development it is evident that the channel in this area is well developed.

The relation of the sound-channel features to the physical oceanography of the area--The

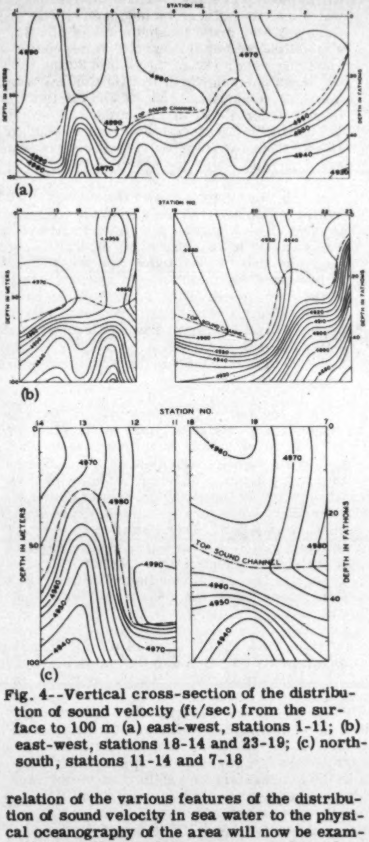


Fig. 4--Vertical cross-section of the distribution of sound velocity (ft/sec) from the surface to 100 m (a) east-west, stations 1-11; (b) east-west, stations 18-14 and 23-19; (c) north-south, stations 11-14 and 7-18

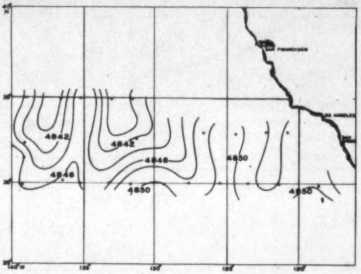

SAN FRANCISCO
LOS ANGELES
4842
4846
4850
140°W
135
130
125
120

Fig. 5--Horizontal distribution of sound velocity (ft/sec) at the sound channel axis

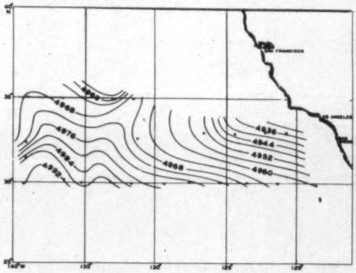

SAN FRANCISCO
LOS ANGELES
4968
4976
4984
4992
4936
4944
4952
4960
4968

Fig. 6--Horizontal distribution of sound velocity (ft/sec) at the top and bottom of the sound channel

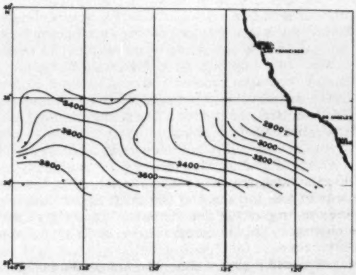

SAN FRANCISCO
LOS ANGELES
3400
3600
3800
2800
3000
3200
3400
3600

Fig. 7--Depth (meters) of the bottom of the sound channel

relation of the various features of the distribution of sound velocity in sea water to the physical oceanography of the area will now be examined in an effort to draw some general conclusions regarding their distribution.

Following Helland-Hansen's original suggestion, a water mass is defined by a curve obtained by plotting temperature as ordinate and salinity as abscissa. This plot of temperature versus salinity is referred to as a T-S curve.

SVERDRUP, JOHNSON, and FLEMING [1942], using this technique, have analyzed all available hydrographic stations in the eastern

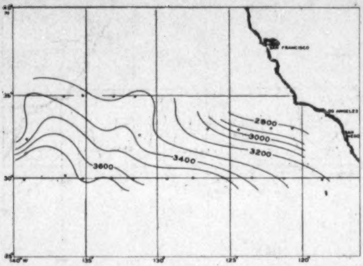


Fig. 8--Width (meters) of the sound channel

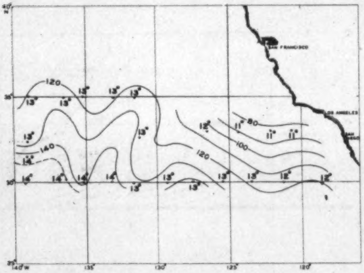


Fig. 9--Difference in velocity (ft/sec) at the top and axis of the sound channel and the angle of the limiting ray

North Pacific and have defined the various water masses. These include a Subarctic Pacific Water mass located north of 45° N, a modified (warmed) Subarctic Water mass along the west coast of the United States to 20° N, an eastern North Pacific Central Water mass located between 135° W and the Hawaiian Islands underlain by an Intermediate Water mass, and a Pacific Equatorial Water mass south of 18° N. These varoius water masses are separated by wide transition zones.

T-S curves were drawn for each of the 23 hydrographic stations and the water masses present at each station determined. At stations 1 to 4 and 19 to 23, located off the California coast, modified Subarctic Water was present in the upper 200 to 300 m. At stations 8 to 13, at the western end of the route, eastern North Pacific Central Water was present to this same depth. At the remaining stations a mixture of water masses was present. At depths greater than 200 to 300 m Intermediate Water was present.

An analysis of the sound velocity data at those stations where only one or the other overlying water mass was definitely present shows that at the sound-channel axis the sound velocity is not significantly different in the two areas. At all stations the channel axis was in the Intermediate Water mass. However, the sound-channel axis is 80 m shallower in the area of the modified Subarctic Water than in the area of the eastern North Pacific Water. This suggests that the warmer and more saline the overlying water mass, the deeper will be the sound channel.

The velocity and depth of the top of the sound channel may be related to the water mass through its relation to the top of the thermocline. Since by definition the velocity at the bottom of the sound channel is equal to the velocity at the top of the channel, the following discussion will be confined to the latter. The average observed depth during this cruise of the top of the thermocline in modified Subarctic Water was 55 m, while in the eastern North Pacific Central Water the depth was 75 m. The average observed depth of the top of the sound channel during this cruise was slightly less, 45 m and 60 m, respectively. The velocity at the top of the sound channel is related to the temperature and salinity of the surface layer. Since the modified Subarctic Water is colder and less saline than eastern North Pacific Water, the sound velocity should be less in the former water mass. Observations bear this out. If the sound velocity were a function of temperature and pressure only, the depth of the top of the thermocline and the top of the sound-channel should coincide, assuming constant temperature in the mixed layer. Since the temperature as observed during this cruise is not generally constant in the mixed layer, but decreases slightly, it is possible for the top of the channel to be shallower than the top of the thermocline. In addition, the variation of salinity in the layer above the top of the thermocline will cause variations in the sound velocity. Since salinity samples were taken only at the surface and 100 m, it is not possible to confirm this feature. However, it is suggested that the top of the sound channel is not greater in depth than the top of the thermocline, since below this depth the temperature, and hence the sound velocity, decrease rapidly.

The width of the observed sound channel is related mainly to the surface temperature. The higher the temperature the higher the velocity at the top of the sound channel. Since below 1200 m temperature and salinity are virtually constant, with respect to time, the sound velocity is primarily a function of depth only. The higher the velocity at the top of the sound channel the greater would be the depth at which the equivalent velocity would be found.

The limiting ray is defined by the difference in sound velocity at the top and axis of the sound channel. This difference is primarily a function of the temperature difference at the surface and the axis depth. The temperature at the axis, in this area, is very nearly 5°C (±0.5°C). The surface temperature varied from about 17°C in modified Subarctic Water to about 20°C in eastern North Pacific Central Water. The salinity is of secondary importance to this velocity difference. At the axis depth the salinity is nearly constant, varying from 33.90 to 34.25 o/oo. At the top of the channel the salinity averages approximately 33.30 o/oo in modified Subarctic Water and 34.60 in Central Water. From this observed variation in temperature and salinity it may be concluded that the channel will be better developed in the warmer more saline water mass.

Application of the sound channel to air-sea rescue--The primary purpose of the Serrano cruise, carried out by the Sofar Research Section of the Navy Electronics Laboratory under Tom McMillian, was to test the accuracy of Sofar network for air-sea rescue purposes by dropping bombs three times a day and comparing the position as obtained by the ship's navigator with that obtained by triangulation. During this cruise 149 bombs were dropped. Of this number six were duds. The remianing 143 shots were heard at all three hydrophone sites except those which were purposely exploded outside the arc of reception for a given hydrophone. In other words a reception of 100 per cent occurred.

Figure 10 presents the results of this bomb dropping program at the 20 positions for which calculations have been completed. The upper figure is the difference in miles between the ship's navigated position (astronomical, Loran, dead reckoning) and that obtained by triangulation. The lower figure is the navigator's estimate of the accuracy of his position determination. This is dependent upon the means (astronomical, Loran, dead reckoning) that were available at the time the position was calculated. At seven of the positions the difference in calculated positions is less than or equal to the estimate of accuracy. At the remaining locations difference in position is very little greater than the estimated accuracy of navigation. The average difference in position determination was 3.5 mi, compared with an average estimate of accuracy of 2.2 mi. The poorest agreement was at station 10, where the position difference was 8.5 mi with an estimate of accuracy of 2.0 mi.

These results are all the more spectacular when it is realized that an average channel-axis sound velocity was used, and it was assumed that the sound was transmitted directly along the axis from sound source to hydrophone via the great circle route, without considering horizontal refraction. The feature of nearly constant velocity along the axis, as well as uniform depth of the axis, is clearly demonstrated by these results.

Conclusions--As a result of this analysis it is possible to draw the following conclusions regarding the distribution of sound velocity in an area in the eastern North Pacific.

(1) The outstanding feature is the presence of a deep sound channel. The axis of this channel is located at a depth of 500 to 700 m, being deeper to the west and south. At the sound channel axis the sound velocity is nearly constant. The presence of this sound channel was previously observed on the E. W. Scripps cruise of 1939 [SVERDRUP, JOHNSON, and FLEMING, 1942, p. 79].

(2) The sound channel is well developed in this area, with the strength of the channel increasing from east to west and north to south.

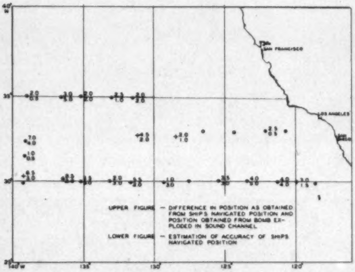

40°N
35°
30°
25°
140°W
135°
130°
125°
120°
SAN FRANCISCO
LOS ANGELES
UPPER FIGURE — DIFFERENCE IN POSITION AS OBTAINED FROM SHIPS NAVIGATED POSITION AND POSITION OBTAINED FROM BOMB EXPLODED IN SOUND CHANNEL
LOWER FIGURE — ESTIMATION OF ACCURACY OF SHIPS NAVIGATED POSITION

Fig. 10--Partial results, in nautical miles, of the bomb dropping program

(3) It appears that all features of the sound distribution may be related to the water mass that is present. In eastern North Pacific Central Water the channel is deeper and better developed than in modified Subarctic Water, while the axis velocity is nearly constant in the two water masses.

(4) The results of the bomb-dropping program were extremely gratifying. The average difference in positions calculated by navigation and by the Sofar network at 20 bomb stations was 3.5 mi, with an average estimate of accuracy of the navigated positions of 2.2 mi.

This study is the result of the first of a series of cruises designed to evaluate the Sofar network and obtain detailed information on the distribution of sound velocity in the eastern North Pacific. Cruises are being planned to obtain data in Equatorial Water and Subarctic Water, to study the distribution of sound velocity around

sea mounts, islands, and in the vicinity of the continental shelf, and to study the annual variation of sound velocity in any given area.

Acknowledgments--The writer acknowledges the assistance of J. S. Black in the work at sea, of Tom McMillian for the use of the data obtained in the bomb dropping program, and of R. Dana Russell, E. C. LaFond, and J. F. T. Saur, Jr. for their critical reading of the manuscript and helpful suggestions.

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OBSERVATIONS ON THE INTRUSION OF ROCK SALT BY PERIDOTITE

John G. Broughton

Abstract--One of the narrow peridotite dikes of central New York has been observed cutting rock salt at a depth of 0.4 mile. It follows one of the regional cross joints and is probably post-Appalachian in age. Structural relationships show mutual intrusion of the peridotite and salt and suggest that the temperature of the tenuous igneous magma only slightly exceeded the melting point of the halite.

In 1947, an ultrabasic igneous dike was found cutting halite in the underground mining operations of the Cayuga Rock Salt Company, near Ithaca, New York (see Fig. 1). This was not entirely unexpected, inasmuch as the mine management and local geologists had been on the lookout for some time for the underground extension of a similar dike exposed at the surface 2175 ft above. It was hoped that rather spectacular contact effects might have occurred where the dike cut the rock salt. The writer was permitted to examine this occurrence in 1948, after additional exposures had been made by further development work.

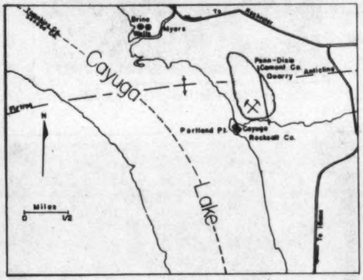


Fig. 1--Map of vicinity of the mine of the Cayuga Rock Salt Co.

The wide spread, but areally unimportant ultrabasic dikes of central New York State have been a subject of recurring interest to geologists since the days of Lardner Vanuxem, and the First New York State Geological Survey. WILLIAMS [1890], KEMP [1891], SMYTH [1902], and many others, have added to our knowledge of these highly altered peridotitic intrusions in an otherwise well-behaved Paleozoic sedimentary terrain.

One typical dike of this group was discovered by SHELDON [1921], and described by her and by LONG [1922]. It was exposed by the quarrying operations of the Penn-Dixie Cement Corp. at Portland Point, N. Y. Here, the dike is exposed intermittently over a strike length of 825 ft in the quarry floor. The country rock is the Upper Devonian Tully limestone, overlain by the dense black Geneseo shale member of the Genesee group. The dike itself varies in width from 12 to 18 inches. Its strike averages N 11°W. This is approximately normal to the axis of the Firtree (Portland Point) anticline, a structure which also may be observed in the quarry. The dike has obviously intruded along a tension (ac) joint, one of the characteristic sets in central New York. This structural relationship is common to all the igneous dikes of the Ithaca region.

The supposed underground extension of the dike is exposed over a length of 300 ft in three headings of the minus 1928 ft level of the mine of the Cayuga Rock Salt Co. The mine workings are along the axis of the Firtree anticline and the adjacent (unnamed) syncline to the north. At this depth the fold axis has twisted to a strike of N 45°W. During the folding, plastic flow of the salt occurred so that the thickness is highly variable and ranges from five feet or less to more than 60 ft. This has forced mining development to be highly selective. Stratigraphically, the salt belongs to the Syracuse salt formation of the Salina group.

The dike underground has a strike averaging N 14°W and dips N 75°W. In one place a very steep eastward dip was observed. The dip, as computed from the surveyed position of the dike exposures at the surface and underground, is 79 1/2°W.

Under the microscope, the igneous dike differs little underground from its appearance at the surface where MARTENS [1924], has called it kimberlite-alnoite, depending on the presence or absence of melilite. Melilite was not observed in the thin sections studied for this paper, although it

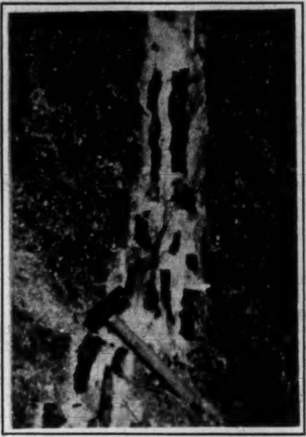


Fig. 2--Separation and support of peridotite breccia by recrystallized rock salt

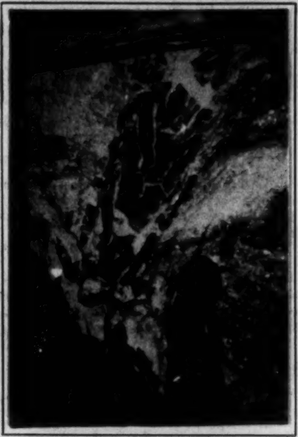
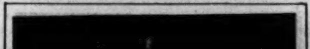


Fig. 3--Peridotite-salt "stockwork"



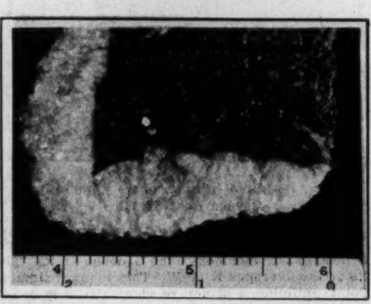


Fig. 5--Comb structure in recrystallized halite

Fig. 4--Salt "ladder-veins" in peridotite dike; limestone inclusions in country rock salt

may have been originally present. The kimberlite is a greenish-gray rock, with prominent olivine phenocrysts that have been altered completely to serpentine. A brown, fresh mica is also characteristically present in phenocrysts. The groundmass consists of a felted aggregate of calcite, serpentine and chlorite. There is no microscopic evidence of any reaction between the igneous rock and the halite. In the specimens of the underground dike, halite has filled cavities and cracks. Calcite has also filled in the centers of olivine phenocrysts in quantities too large to have been supplied by alteration of original melilite. The source is to be sought in the thick limy series penetrated by the dike below the salt. Pyrite is the latest mineral in the sequence and follows salt-dike contacts, encloses olivine phenocrysts and limestone inclusions and generally fills any available voids.

The gross texture of the dike and its relation to the rock salt tell more of the sequence of events involved in its emplacement than does a microscopic study. The most immediately noticeable difference in the dike from its normal surface appearance is the extreme brecciation (see Fig. 2 and 3). The dike is also somewhat narrower than at the surface, ranging in thickness from zero at the pinchout to ten inches. However, it gradually widens northward and may attain a greater width in parts of the salt as yet undeveloped. It is almost invariable to find a tight, frozen contact between the dike and the country salt, which is apparently the only part of the dike which has not been affected by later movement (see Fig. 4). There is no contact effect in the salt at this point, nor is the dike matrix noticeably denser.

Between the selvage and the brecciated dike core is a band up to three inches in width of very clean, white, recrystallized salt, which frequently exhibits well developed comb structure which has obviously started crystallizing outward from kimberlite contacts (see Fig. 4). This is especially characteristic of the symmetrically banded salt-kimberlite complex. However, comb structure is also observed as a radiating structure about breccia fragments and where salt veinlets cut kimberlite (see Fig. 5).

The internal dike core breccia may be broken by regular sets of joints, and filled with recrystallized halite, so as to approximate ladder veins in appearance (see Fig. 4) or by irregular joints, so as to form a halite filled stock work (see Fig. 3). At places, the dike pinches out completely, only to take up again farther along, in echelon fashion (see Fig. 6). A few crystals of salt, similar in appearance to the wall rock salt, have been observed within the kimberlite. Some of these are apparently completely isolated, but show no effects of solution, melting, or recrystallization except for some minor rounding of the outer surface. If these have recrystallized, they have grown from a single point.

The emplacement of the ultrabasic dikes of central New York and western Pennsylvania has been a topic of speculation for years. The most serious difficulty has been to explain how dikes of such narrow width could have remained fluid long enough to have intruded thousands of feet of cold sedimentary rock. In the Syracuse area, angular inclusions of pre-Cambrian syenite are quite common in the dikes and the only obvious source is at a depth of 2500 ft. At Portland Point, the sedimentary sequence is 7000 ft thick. As Martens has indicated, the large number of xenoliths indicate that no great amount of magma moved through the joints. However, he believed the magma to be very fluid and to contain water and other mineralizers. On the other hand, SOSMAN [1938], has deduced, on the basis of the coking of bituminous coal inclusions, that the temperature of intrusions of a similar dike in southwestern Pennsylvania did not exceed 550° C. His concept of intrusion is that of a "hot, plastic stiff mud" with thin films of lubricating liquid "greasing" the differential upward movement of the crystal particles.

The intricate and delicate intrusive relationships of the dike to the salt wall rock makes it difficult to assume any but an extremely fluid magma penetrating the salt beds (see Fig. 7). There is no positive evidence as to absolute temperature at this occurrence. However, the limestone inclusions which are entirely surrounded by dike material have remained unaltered save for a narrow band of bleaching at their outer contact. This effect begins at 600° C at one atmosphere pressure. Furthermore, on the basis of structural relations, it seems necessary to assume that the salt has been rendered fluid by the dike intrusion and remained in that state for a time after the kimberlite had cooled below its freezing point. This is indicated by the development of the dike breccia which has been intimately intruded by the salt but which has been supported by it at all times. The melting point of anhydrous salt at one atmosphere is 801° C. However, the igneous magma apparently contained a large percentage of water in order to become completely serpentinized and chloritized so far below the zone of weathering. Microscopically, there is no difference between the dike at the surface and at depth. It seems entirely possible that the addition of a small amount of water from the dike to the salt would allow it to become thickly fluid at a lower temperature than 800° C. It then acted as a salt magma and as the not yet completely hardened kimberlite pulled away from its frozen wall contacts, the salt found its way into every void around and between dike breccia fragments, at the same time remaining viscous enough to support them (Fig. 2 and 8). As the kimberlite temperature continued to drop, the salt began to crystallize, using dike contacts as foci and then developed the comb structure so characteristic of vein filling (Fig. 9).

To summarize, the sequence of events as visualized by the writer is: (1) Intrusion of a very fluid kimberlite magma in a tension joint or series of parallel joints. (2) As the magma moved upward, it carried with it fragments of limestone, but had insufficient excess heat even to calcine them. (3) As it intruded the rock salt bed, it formed an intricately frozen contact and probably lost heat rapidly through the country rock salt, although the frozen selvage may have acted as a flue lining. (4) Extension of the dike resulted in its being torn away internally from the frozen contacts. As it brecciated, it was intruded by the salt magma. The moving salt supported the dike fragments and

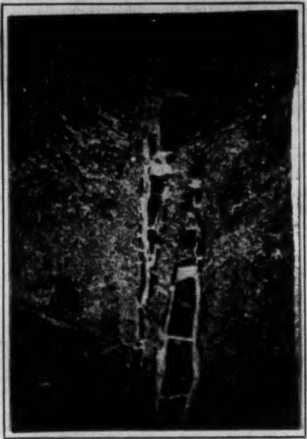


Fig.6--En echelon "pinchouts" in peridotite dike

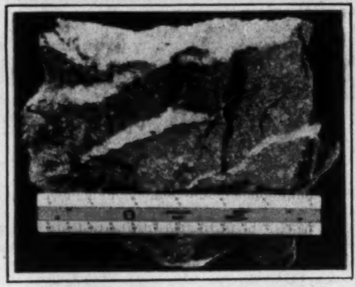


Fig. 8--Salt veinlets in peridotite dike

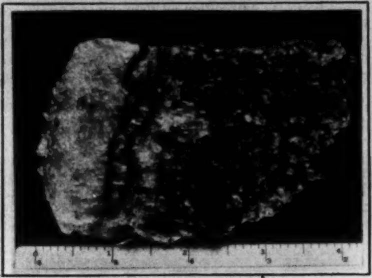


Fig. 7--Peridotite veinlets at contact between recrystallized halite and rock salt

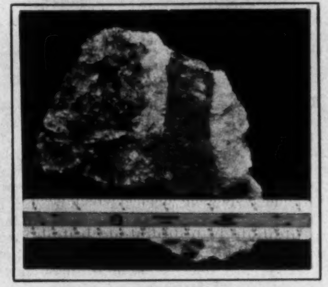


Fig. 9--Recrystallized halite bordering peridotite dikelet

intruded the dike mass. (5) The salt recrystallized under control of the dike fragment contacts.

On the basis of this occurrence, additional support is lent to Sosman's concept of a cooler magma, although the evidence of a tenuous fluid points to a somewhat higher temperature than that which he advocated.

Acknowledgment--The writer was granted every courtesy by the officials of the Cayuga Rock Salt Co., Myers, New York, in carrying on the field work for this report. S. N. Whitman, Engineer, was especially helpful and supplied much valuable information on the mining development.

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INFILTRATION AND RETENTION TESTS AS RELATED TO SPILLWAY DESIGN FLOODS

Paul Leatham and H. S. Riesbol

Abstract--This paper presents a correlation between infiltration rates indicated by field infiltrometer tests, and retention as indicated by studies of the difference between storm rainfall and stream flow for the same area. A measure of the least probable retention which will occur concurrently with a maximum possible rainstorm has been an uncertain factor in the derivation of the maximum probable flood for use in determining the inflow design flood for determining reservoir and spillway capacities. The paper presents results of a series of infiltrometer test runs on plots of ground selected as representative of the various soil - land use complexes to be found under maximum flood hazard conditions in the Kansas River Basin. A comparison is developed between the results of these infiltrometer tests, applied to several storm areas, and the relationship between the retention determined in an analysis of these several storms and the resultant flood runoff. The apparent correlation obtained indicates that infiltration and retention tests can be used successfully to supplement other methods of determining design retention rates and to facilitate the extension and transposition of accepted minimum retention rates to adjacent or comparable drainage areas.

Introduction--The hydrologists of the Bureau of Reclamation are concerned with rates of infiltration and retention as applied in the derivation of the inflow design flood for determining reservoir and spillway capacities. The selection of the inflow design flood used in determining the spillway capacity of a storage dam involves the determination of the computed maximum probable flood. This flood will occur when a maximum possible rainstorm or maximum possible snowmelt takes place concurrently with least probable retention.

The term "retention" is used here to mean the difference between precipitation and direct runoff, thus including all losses of precipitation. The average retention rate is defined as the average rate of loss, usually expressed in inches per hour, such that the volume of rainfall in excess of that rate will equal the volume of direct runoff. In engineering literature this concept has also been referred to as an infiltration index. The customary approach to determining average retention rate involves the analysis of recorded storm events. This is essentially a trial and error process, wherein a fixed initial loss is assumed and an average retention rate is subtracted from hourly rainfall increments. That combination of initial loss and average retention rate by which the observed runoff hydrograph is best reproduced is used in the computation of design flood magnitudes.

The infiltration rate, on the other hand, is the rate, also usually expressed in inches per hour, at which water penetrates the surface of the soil. The final constant or surface minimum infiltration capacity, in inches per hour, is customarily referred to in hydrologic literature as f_c.

The determination of minimum retention rates for use in computing the spillway design flood has been an uncertain task in these flood computations. The usual methods of analyzing a streamflow hydrograph in comparison with the observed rainfall over a drainage basin area entail numerous shortcomings for application in the West. The short period of recent stream-flow and rainfall records and the sparseness of the old hydrologic network, the remoteness of most reclamation areas from the sources of moist air masses, and the requirement that an intense storm cover most of the basin area for which retention rates are to be determined has resulted in our obtaining no dependable retention values for many of our drainage areas.

Infiltration tests--To supplement the use of the storm-hydrograph analysis and to facilitate the extension and transposition of accepted values of retention for use in adjacent or comparable drainage areas, it was decided to perform a series of actual infiltration tests, with a portable infiltrometer, upon plots of ground representative of various soil types.

The area selected for the first series of tests was an area of western Kansas and eastern Colorado draining into the Smoky Hill and Republican River tributaries of the Kansas River Basin.

Table 1--Preliminary grouping of infiltration complexes for locating test plots

Relative infiltration	Soil complexes	No. of plots required
Low	Crete-like silt loams	2
Low	Hastings-like silt loams	2
Low	Keith-like silt loams	2
Low	Lithosol soils overlying Niobrara	2
Medium	Ulysses silt loam	2
Medium	Colby silt loam, cultivated	2
Medium	Colby silt loam, pasture	2
Medium	Weld silt loam	2
Medium	Rogo silt loam	2
High	Ascalon sandy loams	2

Arrangements were made with the Bureau of Plant Industry, Soils, and Agricultural Engineering at Lincoln, Nebraska, and with the Soil Conservation Service and State Experiment Station at Manhattan, Kansas, to obtain a classification and grouping of the soils within the Kansas River Basin according to their potential infiltration characteristics. Emphasis was placed upon the selection of broad general classifications for the major infiltration groups. The best basis readily available to guide us in forming these classifications was the experience and judgment of the soil scientists consulted. Three major infiltration groups were selected (see Table 1) with tests planned on the principal soil types constituting each group. Duplicate plots were selected for each of these soil types at various locations in the Kansas River Basin (see Fig. 1). The locations of the test plots are shown on the map beginning with the low infiltration types which occur in the eastern portion of the drainage area and progressing westward into the medium and high infiltration groups.

A modified Type F infiltrometer apparatus and trained crew were available from the Bureau of Reclamations' Valley Gravity Project, Texas. The infiltrometer was designed, constructed, and assembled for the Valley Gravity Project in the Bureau of Reclamation shops of the W. C. Austin Project, Altus, Oklahoma. It is patterned after the Type F infiltrometer as developed by the Soil Conservation Service, which agency furnished drawings used as a guide in the design and construction of the infiltrometer.

This infiltrometer consists essentially of two parallel lines of six nozzles each (see Fig. 2) on each side of a bordered study plot, six by ten feet. Each bank of nozzles is equipped with a pressure gage and a regulating valve for controlling the rate of sprinkling. A gang of metal hoods can be simultaneously interposed over the nozzles to divert the spray into waste drain troughs. Simulated rainfall at a constant rate is uniformly applied to an area about 12 × 16 ft with this apparatus.

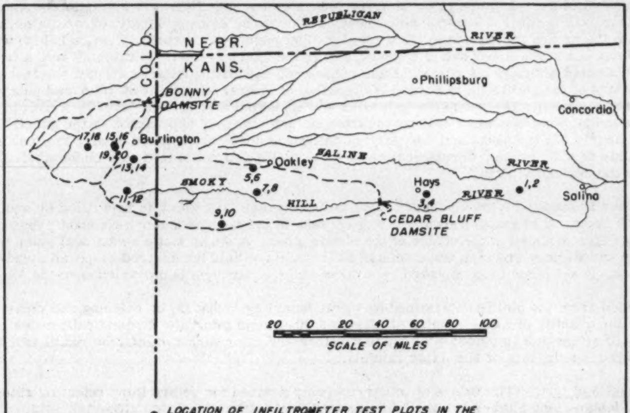
REPUBLICAN
RIVER
NEBR.
KANS.
COLO.
BONNY DAMSITE
Phillipsburg
Concordia
17,18
15,16
Burlington
19,20
13,14
Oakley
SALINE
RIVER
5,6
SMOKY
7,8
11,12
HILL
9,10
Hays
3,4
RIVER
1,2
Salina
CEDAR BLUFF DAMSITE
20 0 20 40 60 80 100
SCALE OF MILES
● LOCATION OF INFILTROMETER TEST PLOTS IN THE SMOKY HILL AND REPUBLICAN RIVER BASINS.

Fig. 1--Location map

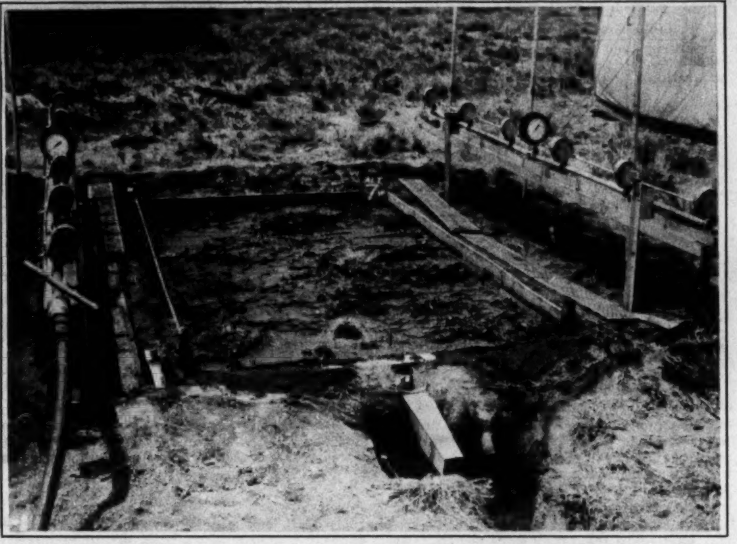

Fig. 2--Infiltrometer apparatus after completion of test; hoods are over nozzles and the tent and runoff trough cover have been removed

The free fall of the raindrops is about seven feet, a distance sufficient to approximate the terminal velocity of falling rain. The study plot is enclosed on three sides by metal border plates, which extend into the ground far enough to form a water-tight boundary. A runoff plate, set flush with the ground surface at the lower end of the plot, allows the excess rainfall to drain off into a trough and through a spout where it can be caught and measured. Sprinkling an area about three feet beyond the borders of the plot tends to minimize the effect of lateral movement of water and entrapped air through the subsoil. The sprinkler apparatus and sprinkled area are enclosed by a canvas tent to provide protection from winds that could affect the uniformity of application or the runoff. Controls for the nozzle line pressure and the gangs of deflecting hoods are located outside the tent, making it possible to start or stop the application of water at the full calibrated rate instantaneously from outside the sprinkling area.

Water is supplied from a portable 3000-gallon storage tank which is kept filled by hauling water in a tank truck. It is pumped from the storage tank to the nozzles under a constant pressure, measured by gages mounted in the center of the nozzle pipes. A single stage centrifugal pump was not entirely satisfactory since on some occasions it would not hold the desired 34-pound steady operating pressure. It has since been replaced by a three-stage centrifugal pump which does the job quite well.

Runoff from the plot is determined by "grab sampling," that is, by catching and measuring frequently the quantity of water running off during a 30-second interval. A metal calibration pan the same size as the plot is placed over the plot before and after each run, and the runoff rate from the pan is taken as the rate of simulated rainfall.

Results of tests--The values of infiltration rate desired for determining retention rates to be used in design-flood studies are the minimum constant infiltration rates ultimately attained by prolonged rainfall on a previously wetted area, assuming cover and soil conditions conducive to maximum runoff. Such rates probably would occur on an essentially denuded drainage basin such as might result from drought or land misuse. To simulate these conditions the vegetation present at the test sites is removed by clipping as close as possible without disturbing the plant roots. To assure comparable antecedent moisture content, and to duplicate maximum flood hazard conditions, the plot area is thoroughly pre-wetted by sprinkling 24 hours previous to the test run.

Results of each run are plotted on rectangular coordinates with runoff rate (q) in inches per hour versus time in minutes. A horizontal line indicating the rate of simulated rainfall (i) is drawn and an apparent infiltration, or (i - q) curve computed. Since the primary concern is with minimum probably retention rates and these are based on derived values of the final constant infiltration capacity, f_c, no attempt has been made to correct the i - q curve to a true infiltration capacity curve.

When the runoff and infiltration capacity have become constant, (i - q) becomes equal to f [HORTON, 1942], therefore, values of f_c are taken directly from the relatively horizontal portion at the end of the (i - q) curve. Figure 3 shows a typical plotting of one of the low infiltration group plots. The soil type is Hastings silt loam, level slope, with a cover crop of young wheat which was clipped off to a height of one inch and the clippings removed before beginning the test. This test was run for a period of 70 min. The plotted values of runoff samples are fitted by a runoff curve, and an (i - q) curve determined. The value of f_c taken from the end of the (i - q) curve is in this test 0.20 in/hr. Similar curves, prepared for each test plot show for Lithosol soil on Niobrara chalk, pasture cover, three-hour test run, a constant infiltration rate of 0.52 in/hr; for Rago silt loam, in the medium infiltration class, volunteer wheat and stubble clipped and removed, three-hour test, an f_c of 0.28 in/hr; and for the high infiltration group, Ascalon and similar sandy loam soils, wheat stubble cover clipped and removed, an f_c of 0.37 in/hr from a three-hour infiltration test.

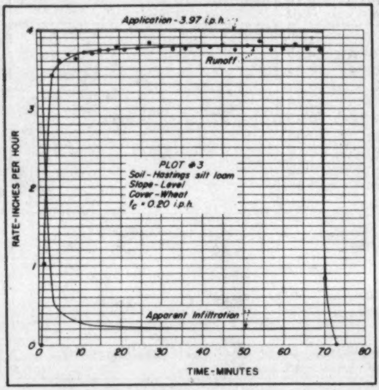

Fig. 3--Typical curve of runoff and apparent infiltration indicated by infiltrometer tests

After determining values of f_c in this manner for each plot tested, soil specialists from the Bureau of Plant Industry, Soils, and Agricultural Engineering, and the Soil Conservation Service were again consulted to discuss the tests and the application of results on a drainage area basis. As a result of these discussions and the test results, a revision of the major infiltration groups was made as shown in Table 2. It was agreed that about 50 per cent of each of the various soil types should be considered as having either a vegetated or trash tillage cover even in the maximum flood hazard case, and minimum infiltration rates for such cover conditions were estimated as shown in the table. The relatively high infiltration rates for the Lithosol pasture lands required removing those tests from the low infiltration group and a separate consideration of those lands as a fourth group. The table shows for the low infiltratoin group consisting of Crete, Hastings, and Keith silt loams, f_c rates varying from 0.16 to 0.23 in/hr or an average test value of 0.19 in/hr for the bare cultivated test plots and an estimated vegetated and trash tillage rates again were heavily dependent on the experience and judgment of the group of soil scientists consulted. They were arrived at with the aid of records of the Soil Conservation Service, Experiment Station, and Bureau of Plant Industry, Soils, and Agricultural Engineering; mostly unpublished data from field infiltrometer tests. For the medium infiltration group, rates range from a low value of 0.16 in/hr to 0.39 in/hr averaging 0.30 in/hr with an estimated rate of 0.50 in/hr for vegetated and trash tillage cover on this group. For the sandy loams, a rate of 0.37 in/hr was determined with an estimated 0.70 in/hr on vegetated and trash tillage cover. The Lithosol soil overlaying Niobrara chalk is considered to be practically all pasture land and the test average f_c, 0.53 in/hr, is taken also as the vegetated rate.

Application of test data--In applying the infiltration rates determined for the four groups on a drainage area basis, the Smoky Hill River Basin above Cedar Bluff Damsite was chosen for the first trial. An analysis of the west Kansas breaks and canyons area with respect to soil conditions which may affect runoff was available prepared by the Soil Conservation Service and the State Experiment Station at Manhattan, Kansas. The various groupings and acreages listed in this analysis were correlated with the four infiltration groups as shown in Table 3.

A county by county analysis, weighting acreages of each of the four groups and relative vegetated areas, gave a final minimum infiltration value for the 5300 sq mi drainage area of Smoky Hill River

Table 2- Infiltration complexes regrouped with the aid of the f_c values determined in the testing program

Relative infiltration	Group	Test plot	Infiltration complex	f_c	Group average fc	Group estimated f_c for vegetated and trash tillage cover
				in/hr	in/hr	in/hr
Low infiltration	1	1	Crete silt loam	0.22	0.19	0.25
		2	Crete silt loam	0.23		
		3	Hastings silt loam	0.20		
		4	Hastings silt loam	0.16		
		5	Keith silt loam	0.18		
		6	Keith silt loam	0.17		
Medium infiltration	2	9	Ulysses silt loam	0.39	0.30	0.50
		10	Ulysses silt loam	0.36		
		11	Colby silt loam	0.27		
		12	Colby silt loam	0.29		
		19	Colby silt loam	0.29		
		20	Colby silt loam	0.32		
		13	Weld silt loam	0.16		
		14	Weld silt loam	0.23		
		15	Rago silt loam	0.35		
		16	Rago silt loam	0.28		
Ascalon-like soils	3	17	Ascalon sandy loam	0.37	0.37	0.70
		18	Ascalon sandy loam	0.37		
Lithosol pasture lands	4	16	Lithosol on Niobrara	0.52	0.53	0.53
		17	Lithosol on Niobrara	0.54		

Table 3--Correlation of soil conditions which may affect runoff with infiltration groups for the West Kansas Breaks and Canyons Area

Soil types	SCS unit classification	Infil. group
Deep and mod. deep, silty to friable clayeys on upland, benches and bottoms	1	2
Moderately deep, heavy clay soils on nearly level benches	2	1
Moderately deep, silty to friable clayey soils on gently sloping land with slight to moderate erosion	3	2
Mixed sandy and very sandy soils with sandy to clayey subsoils	4	3
Shallow, silty soils on uplands and benches (loess and outwash), nearly level, moderate wind erosion	5	2
Shallow, silty soils on gently sloping uplands - from loess, outwash and chalkrock	6	2
Shallow and very shallow, silty to loamy soils of sloping uplands from outwash, loess and chalkrock	7	4
Medium to heavy textured, poorly drained soils of bottoms and depressions	8	2
Moderately deep to shallow, heavy clay soils from shales	9	1
Very sandy soils on hummocky uplands and benches (includes some sandy bottomland)	10	3
Shallow, stony or gravelly soils (principally from Ogallala)	11	1
Shallow, silty soils from chalk rock and shale (includes some raw areas)	12	1
Shallow, stony, gravelly and shaley soils on broken, steep uplands (Ogallala and cretaceous beds mixed)	13	1
Sand dunes and sands	14	3
Principally raw areas of chalkrock and shale	15	1
Riverwash sands and gravels	16[a]	. . .

[a] This very small portion of the drainage areas was considered as non-contributing to flood runoff in most cases, or treated as Group 4, where applicable in this analysis.

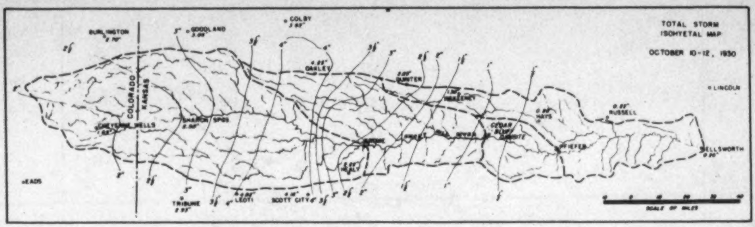
TOTAL STORM
ISOHYETAL MAP
OCTOBER 10-12, 1930
BURLINGTON
GOODLAND
COLBY
COLORADO
KANSAS
OAKLEY
CHEYENNE WELLS
SHARON SPGS
HAYS
RUSSELL
LINCOLN
CEDAR BLUFF DAMSITE
PFEIFER
ELLSWORTH
HEALY
EADS
TRIBUNE
LEOTI
SCOTT CITY
SCALE OF MILES

Fig. 4--Storm of October 10-12, 1930, Smoky Hill River Basin, Colorado and Kansas

Basin above Cedar Bluff Damsite equal to 0.39 in/hr.

As a comparative evaluation of minimum infiltration rates derived by infiltrometer analysis versus minimum constant retention rates determined from storm rainfall analysis over the Smoky Hill region, consider the storm of October 1930. This storm (see Fig. 4) occurred over the lower portion of the Cedar Bluff drainage area and was gaged at Jerome and Pfeifer. In each case a balance was determined between assumed initial losses and constant retention rate. That combination by which the hydrograph was most nearly reproduced was accepted. For the area above Jerome, an initial loss of 2.0 inches and constant retention rate of 0.32 in/hr was indicated while for the area above Pfeifer, the initial loss was 2.0 inches and the constant retention rate 0.29 in/hr. Application of rates determined in the infiltrometer tests to the areas determined to be contributing to the run-off in each case (the area within the two-inch isohyet) indicates minimum constant infiltration rates of 0.39 in/hr for the area above Jerome, and 0.36 in/hr for the area above Pfeifer.

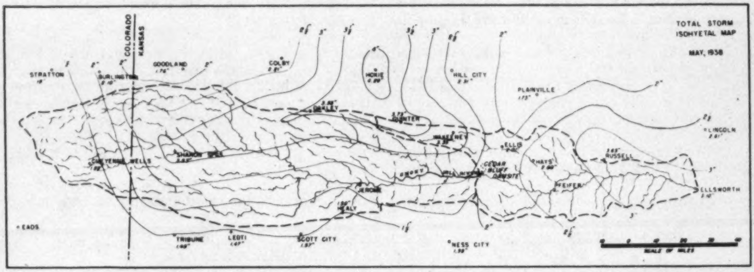
TOTAL STORM
ISOHYETAL MAP
MAY, 1938
COLORADO
KANSAS
STRATTON
BURLINGTON
GOODLAND
COLBY
HOXIE
HILL CITY
PLAINVILLE
OAKLEY
GRINNELL
WAKEENEY
ELLIS
HAYS
RUSSELL
LINCOLN
SHARON SPGS
CHEYENNE WELLS
SMOKY
HILL RIVER
CEDAR BLUFF DAMSITE
JEROME
PFEIFER
ELLSWORTH
HEALY
EADS
TRIBUNE
LEOTI
SCOTT CITY
NESS CITY
SCALE OF MILES

Fig. 5--Storm of May 1938, Smoky Hill River Basin, Colorado and Kansas

Similar computations were made for the storm of May 1938 (see Fig. 5). This storm also occurred over the lower portion of the drainage basin. The flood was gaged farther downstream at Ellsworth. The best reproduction of the flood hydrograph was obtained in this case with an initial loss assumption of 1.0 inch and a constant retention rate of 0.32 in/hr. Application of the results of the infiltrometer tests indicate a minimum constant infiltration rate of 0.39 in/hr.

A second drainage basin, the Republican River Basin above Bonny Damsite, was selected for comparison of the infiltrometer determined rates with rates determined from storm hydrograph analysis. A classification, based upon correlation of soils and cover found in the Republican River drainage area with the west Kansas breaks and canyons area, had also been prepared by the Soil Conservation Service and the State Experiment Station at Manhattan, Kansas. The various groupings and acreages were further correlated with the four infiltration groups adopted earlier and were weighted in a county by county analysis to give a weighted average infiltration rate of 0.44 in/hr for the 1495 sq-mi area above Bonny Damsite.

A storm hydrograph analysis can be made for this area from the storm of May 30-31, 1935 (see Fig. 6). The center of this storm occurred near Burlington, Colorado, within the Republican

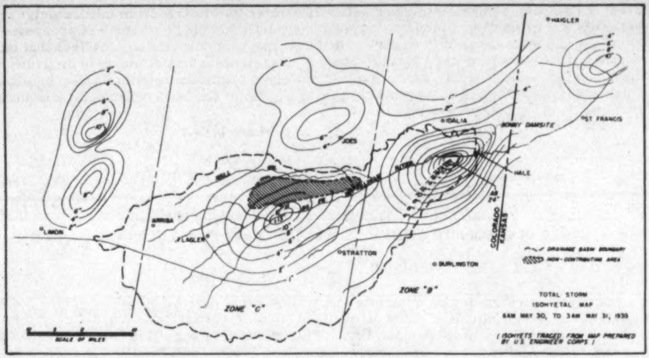
HAIGLER
ST FRANCIS
IDALIA
BONNY DAMSITE
JOES
HALE
LIMON
ARRIBA
FLAGLER
STRATTON
BURLINGTON
COLORADO
KANSAS
ZONE "B"
ZONE "C"
DRAINAGE BASIN BOUNDARY
NON-CONTRIBUTING AREA
TOTAL STORM
ISOHYETAL MAP
6AM MAY 30, TO 3AM MAY 31, 1935
(ISOHYETS TRACED FROM MAP PREPARED BY U.S. ENGINEER CORPS)
SCALE OF MILES
2"
4"
6"
8"
10"
24"

Fig. 6--Storm of May 30-31, 1935, Republican River Basin, Colorado

River Basin. The isohyetal pattern determined by the Corps of Engineers in their study of this storm shows a good fit over the lower portion of the drainage area above Bonny Damsite. The starting time of the flood, the peak value of 103,000 cfs, and a description of the recession were obtained from the United States Geological Survey Water Supply Paper 796-B. This information provided the basis for producing a flood hydrograph for a point near the Bonny Damsite.

This flood hydrograph was most nearly reproduced by using an initial loss assumption of 2.0 inches of rainfall and a constant retention rate of 0.40 in/hr. Using the previously mentioned correlation of soils and cover in the drainage area above Bonny Damsite with the four major infiltration groups, a minimum average infiltration rate of 0.49 in/hr is determined for the area assumed contributing in the storm hydrograph analysis, that is the area within the two-inch isohyet.

The summarized comparisons made above are shown in Table 4. Attention is called to the uniformity of the ratios shown in the last column.

Conclusions--The results of this program are encouraging to the flood hydrologist. We have

Table 4--Comparison of retention rates determined from storm hydrograph analysis with infiltration rates derived from infiltrometer tests

Storm	Drainage area	Infiltration rate[a]	Storm hydrograph		Ratio[b]
			Initial loss	Constant retention rate	
		in/hr	inch	in/hr	
Oct. 1930[c]	Smoky Hill River above Jerome, Kans.	0.39	2.0	0.32	1.22
Oct. 1930[c]	Smoky Hill River above Pfeifer, Kansas	0.36	2.0	0.29	1.24
May 1938[d]	Smoky Hill River above Ellsworth, Kansas	0.39	1.0	0.32	1.22
May 1935[d]	Republican River above Bonny Damsite	0.49	2.0	0.40	1.22

[a] Minimum infiltration rate as determined from infiltrometer test.
[b] Ratio of infiltrometer rate to rate determined from the storm hydrograph.
[c] Maximum storm of record.
[d] Only storm in these basins for which sufficient data are available.

an apparent correlation between minimum infiltration rates determined from infiltrometer tests and minimum retention rates determined by storm hydrograph analysis. Further test programs in other drainage areas will serve to modify or strengthen this apparent correlation. We feel that infiltration and retention tests can be used successfully to supplement the use of storm hydrograph analyses, and to facilitate the extension and transposition of accepted minimum retention rates to adjacent or comparable drainage areas. This should be of great benefit to the flood hydrologist concerned with the determination of the spillway design flood.

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U. S. Bureau of Reclamation,
Denver, Colorado

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DISCUSSION

John A. Adams, Jr. (Intermountain Forest and Range Experiment Station, Forest Service, Ogden, Utah)--The study of infiltration by applying simulated rainfall to sample plots, has developed largely during the past 20 years. One of the most important results of these tests to date has been the recognition that it is a very complex problem with many of the overall answers still to be attained. It is generally agreed that without actual testing it is hazardous to attempt to assign estimates of infiltration rates to any soil or vegetal cover condition or group of complexes. It is also difficult to transpose measured values from one site to other sites that appear to be similar. These difficulties are borne out in the present paper where the shallow pasture soils which were assigned a low rate at the beginning of the study on the basis of soil investigation, were later, as a result of infiltration runs, placed in the highest rates, apparently due to more ground cover. This situation definitely indicates the absolute necessity for actual tests on the ground in order even to approach the relative placement of the infiltration rates by various soil and cover conditions. While numerous infiltration rates have been obtained from plots containing a variety of soil and cover conditions, only a limited amount of research has been done on the phase of expansion of the plot data to obtain estimates of areal infiltration rates for watershed areas. Results to date indicate that this phase should be done very cautiously with realization that while the results obtained probably show the relative placement of infiltration rates by various plant cover soil conditions the actual areal rates may be at considerable variance from derived values, even though a satisfactory check on the observed hydrograph may be obtained.

It is noted that some difficulty was encountered in maintaining the necessary water pressure in the Type F machine during the runs. This and other difficulties encountered by other investigators including variation in rainfall pattern on the plot, inability to ascertain the rainfall intensity during the run, effect of splash on the open collector trough, has led to the development by the Intermountain Forest and Range Experiment Station of a new model of the Type F. The Intermountain Type F machine constructed in 1947 utilizes many of the features found in the Type F, details are shown in Figure 7. The Type F nozzle was used essentially unchanged as far as sprinkling characteristics were concerned. Heads are attached to a ball and socket joint to provide ease in obtaining the same rainfall pattern on all slopes. A much steadier distribution system was obtained by providing each nozzle with a direct supply line from the surge tank. Plot size is six × six feet. The trough gages along each side of the plot provide a means to measure rainfall during the actual run instead of using a rate obtained before and after the run. The infiltrometer is usually operated with intensities ranging between three and six inches per hour. Calibration runs indicated a rainfall pattern on the plot with 10 to 20 per cent variation which is a considerable improvement over the Type F.

The paper indicates that the rainfall rates applied varied between three and four inches per hour. Inspection of rainfall data from the larger storms occurring in this region indicate higher rainfall intensities were experienced than those used. In order to obtain comparable results with those occurring in the larger type storm, it would appear that rainfall should be applied at higher intensities.

It is noted that originally the plants on the plots were clipped to simulate a denuded condition

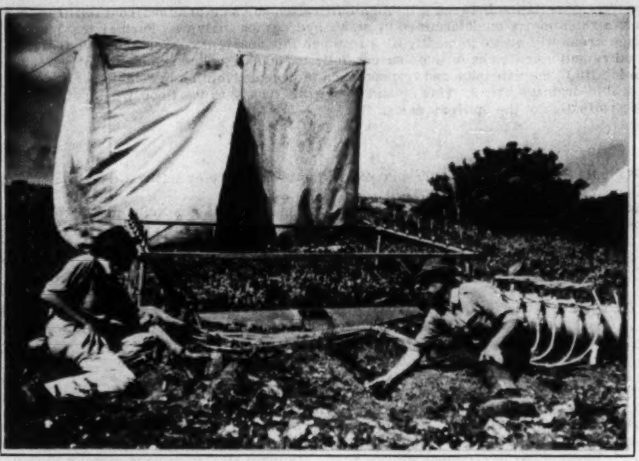

Fig. 7--Intermountain type F infiltrometer; photography by U. S. Forest Service

and later adjustments were made in the observed rates to take into account plant cover and litter. The importance of plant and litter cover is well borne out by our studies. We have found as a result of many hundreds of infiltrometer runs and related studies on a wide variety of plant cover soil condition with few exceptions, that infiltration rates are directly related to the amount of ground surface covered by living plants and litter.

The living plants and litter not only have a surface mechanical effect on breaking up the raindrops but the associated biologic activity, organic matter and root systems in the soil play an important role in determining the initial as well as the final infiltration rate.

Data are not given in the paper to ascertain how initial losses which vary from one to two inches were derived. A suggested method in addition to recognized methods for ascertaining field moisture condition as reflected by ground water discharge is to utilize data from dry runs on the plots versus wet runs on the same plots. Data resulting from this study can also be utilized to adjust infiltration rates for different seasons during the year.

The infiltration rates in the paper appear to be of the right order of magnitude for the wet soil condition and large storms used. During most storm conditions where antecedent conditions do not result in such wet soils the infiltration rates for the area considered are probably greater.

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ESTIMATING DATES OF RECENT GLACIER ADVANCES AND RECESSION RATES BY STUDYING TREE GROWTH LAYERS

Donald B. Lawrence

Abstract--Study of the growth layers of trees growing along the margins and below the terminus of a present day receding glacier reveals the minumum lapse of time in years since the glacier advanced beyond a given point, and the approximate rates at which recession has occurred. Study of cross sections of trees pushed part way over by ice pressure at the time of maximum glacier advance and left in a tilted position to continue growth until the present, discloses the exact year of the maximum advance. This is detected through a change in form of growth layers in the trunk cross section. Growth while the tree is erect is concentric about the growth center; that after trunk tilting is asymmetric. The non-conformity between concentric central growth and eccentric outer growth marks the year of the tilting. This technique and others described here may be used to date landslides, windstorms, and river floods as well as glacier fluctuations.

Introduction

A new sub-committee on "Ecology as Related to Glacier Studies" within the Committee on Glaciers of the Section of Hydrology was formed in the spring of 1949, with the writer as Chairman. The chief objectives are to aid in promoting more field studies and to act as a clearing house for information on this aspect of glaciology. It is hoped that this article on methods will encourage research in this direction.

The application of tree ring study to the solution of problems of recent glacier history is not new. Some of the phases of the method have been used in North America over a period of many years by TARR and MARTIN [1914], COOPER [1923, 1931, 1939], and the writer [LAWRENCE, 1946b] in southeastern Alaska; by BUTTERS [1914], COOPER [1916] and Mathews [personal communication May 1, 1949] in British Columbia; and by the writer [LAWRENCE, 1948] in Oregon. A description of the technique has been published [LAWRENCE, 1946a] in preliminary form only. Since the technique is relatively simple, it should be applied to local studies wherever possible over a broad geographic range so that accurate correlations and generalizations regarding past climatic and glacier fluctuations may be made in the near future. In the suggestions set forth below, the possibilities and limitations of the method have been emphasized in the hope that similar work planned by others may provide maximum returns on the effort expended in the collection of the material.

What to look for

In the Pacific Northwest of the United States, southwestern Canada, and southeastern Alaska, and apparently also in other regions widely distributed throughout the world [MATTHES, 1942, 1946], wherever glaciers occur today, many glaciers have advanced within the past 1000 years and then receded again. There exist evidences today by which estimates of the amount of time that has elapsed since the recent maximum, and also of rates of recession, can be worked out. Study of stereoscopic pairs of vertical aerial photographs which show the lower reaches of a glacier and the forested terrain beyond the terminus, aid very greatly the search for particularly fruitful study areas. The clues may be classified as follows.

The trimline--After a little careful study of aerial photographs and observation in the field, it will be noticed that any glacier that has recently advanced down a forested valley, has destroyed all the forest in its path. At the line representing the maximum position attained by the ice front, where the forest was sheared off by the ice, is a sharp transition called the "forest trimline" (see Fig. 1, F-G); it is a region of extreme usefulness for accurately dating the maximum advance, as will be noted in detail below.

Age of undisturbed forest beyond the position of maximum advance--The age of the oldest tree growing just beyond the end moraine or outside the lateral lines of maximum extent, provides a minimum estimate of the time that has elapsed since the glacier extended beyond that limit. If there are in that old forest many old extensively decayed logs lying about on the forest floor, and especially if any of the present generation of old trees are growing astride the old decayed logs (see Fig. 1, D-E)

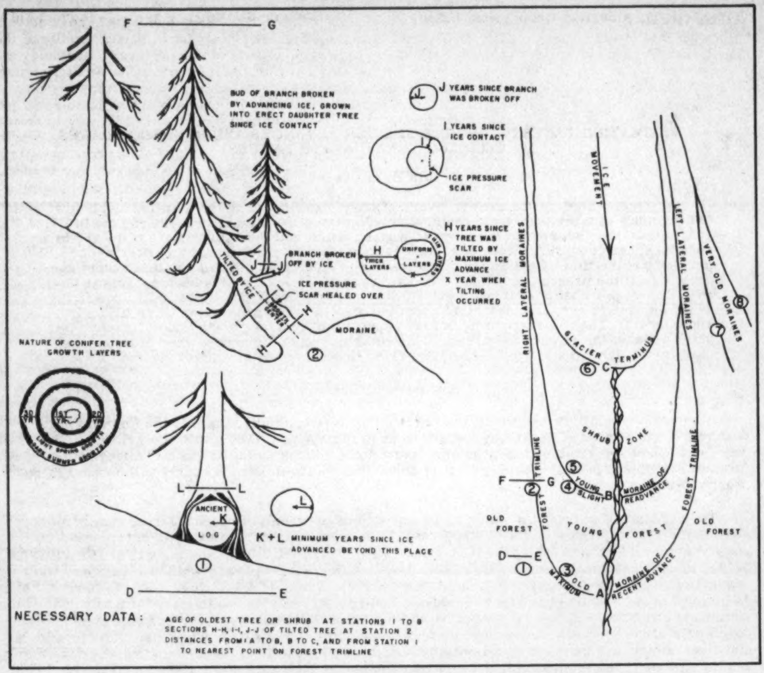
F — G
BUD OF BRANCH BROKEN BY ADVANCING ICE, GROWN INTO ERECT DAUGHTER TREE SINCE ICE CONTACT
J YEARS SINCE BRANCH WAS BROKEN OFF
I YEARS SINCE ICE CONTACT
ICE PRESSURE SCAR
H YEARS SINCE TREE WAS TILTED BY MAXIMUM ICE ADVANCE
X YEAR WHEN TILTING OCCURRED
THICK LAYERS
UNIFORM LAYERS
THIN LAYERS
TILTED BY ICE
BRANCH BROKEN OFF BY ICE
ICE PRESSURE SCAR HEALED OVER
GROWTH CENTER
MORAINE
②
NATURE OF CONIFER TREE GROWTH LAYERS
1ST YR
2D YR
3D YR
LIGHT SPRING GROWTH
DARK SUMMER GROWTH
L — L
ANCIENT LOG
K
K + L MINIMUM YEARS SINCE ICE ADVANCED BEYOND THIS PLACE
①
D — E
NECESSARY DATA: AGE OF OLDEST TREE OR SHRUB AT STATIONS 1 TO 8
SECTIONS H-H, I-I, J-J OF TILTED TREE AT STATION 2
DISTANCES FROM A TO B, B TO C, AND FROM STATION 1 TO NEAREST POINT ON FOREST TRIMLINE
ICE MOVEMENT
RIGHT LATERAL MORAINES
LEFT LATERAL MORAINES
VERY OLD MORAINES
⑧
⑦
GLACIER TERMINUS
⑥ C
SHRUB ZONE
FOREST TRIMLINE
⑤
④
YOUNG SLIGHT B MORAINE OF READVANCE
OLD FOREST
YOUNG FOREST
OLD FOREST
③
OLD MAXIMUM A MORAINE OF RECENT ADVANCE

Fig. 1--Diagrammatic summary of methods used in estimating dates of recent glacier advances and rates of recession by tree growth layers

then the minumum time interval can be reasonably estimated to be much longer than the age of the oldest living tree. Sometimes such decaying straddled logs are in good enough condition to enable one to count the growth layers, and in such cases the ages of the log and of the tree growing on it are added together to obtain the minimum estimate of time lapse (see Fig. 1, K + L). The thickness of the organic layers of the forest floor and the degree of development of the soil profile provide collateral evidence of forest age.

Age of young forest grown up on deglaciated terrain-- As the glacier receded from its position of maximum advance, new land surfaces were exposed, on which tree seedlings could begin to grow, and in some places it is easy to distinguish at a glance the new forest that has grown up, from the undisturbed old forest beyond the trimline, but in other places the young forest is already so old that the position of the trimline may escape early detection by an inexperienced investigator. Even two centuries or more after the ice has begun to recede, the line that divides the old and young forests may stand out in a distant view and in aerial photos as sharply as though cut with a knife. The age of the oldest tree growing between the position of maximum advance and the present ice terminus provides a minimum estimate of the time that has elapsed since the ice began to recede. Within the region of recent glaciation, between the line of maximum advance and the present ice-front, a series of younger and younger trees and shrubs will be found; and often also, a series of small recessional moraines that form curved ridges, convex down hill, extending across the valley (see Fig. 1, B). The ages of the oldest trees or shrubs growing at various positions in this progressively younger forest will provide a reasonable estimate of the rate at which recession occurred and the approximate dates at which the recessional moraines were formed.

So far the procedure outlined here has been simply a count of the total number of growth layers produced between the growth center of the trunk and the inner edge of its bark, during the life of the woody plant; these layers are normally laid down at the regular rate of one per year. Obviously the procedure applies not only to the region between the end moraine and the current ice front, but also to the area between the outermost lateral moraines and the present lateral edges of the ice. The counts derived from trees growing along the lower ice-freed terrain give a more reliable estimate of total time lapse than those growing farther up the slope because of the closer proximity to abundant seed source and more favorable climatic conditions at the lower altitude. But the dates provided by this method are only relatively rough estimates for three reasons: (a) The oldest tree in a particular area of forest is not necessarily the largest tree; the oldest cannot be found without testing many trees, and there is rarely time to do that. (b) It may be impossible to obtain a sample of the wood from bark to center at the level which was the base of the stem when the tree seed germinated. (c) An unknown amount of time elapses between complete melting of the ice and the germination of the first shrub or tree seed that grows on to maturity.

At our present stage of knowledge we have very little information to improve the accuracy of estimating from these woody plants, but we do know that the time estimated may be either too long or too short. It may possibly be too long, because in some cases trees and shrubs have been found growing on the rock debris on a receding glacier surface, at least twenty years before the ice has melted out, and while the glacier is still in motion [LAWRENCE, 1948]; it is doubtful, however, that such individuals ever survive the violent transplanting that must take place with slumping of the debris at the melting ice terminus. The growth layer record is much more likely to be too short because the establishment of a tree seedling at timberline probably requires the combination of a good seed year, a year of low rodent population, a favorable climatic period, and suitable soil conditions. Such a coincidence could be expected to occur only rarely on newly deglaciated terrain, and establishment of the first tree seedling may take a half century after recession of the ice. The best way to improve our estimates of this time lapse will be to study old photographs of receding glaciers, taken at known dates, and to watch carefully by repeatedly mapping the woody plants over a half century or more, the progress of vegetation development on recently deglaciated terrain.

Date of tilting or injury of trimline trees by contact pressure of ice at maximum advance--The date of maximum ice advance can be ascertained accurately at once to the very year, from certain special trees without old photographs or vegetational development studies. The old trees which formerly grew erect along the line of maximum advance and which have been pushed part way over by the action of the ice, and left to continue their growth in a tilted position, give such an accurate answer (see Fig.1,H). During the early period of life when a tree is erect, the growth layers as seen in cross section, form in concentric rings about the center; after a tree is tilted, however, the rings form eccentrically [PILLOW and LUXFORD, 1937] so that in conifer trees 80 per cent or more of the wood may have formed on the lower side of the growth center (see Fig. 2, Q-R); in many broadleaf deciduous trees the situation is reversed so that the greatest growth occurs on the upper side of the trunk following tilting (see Fig. 2, S-T). But in either case, the junction of the concentric inner layers with the eccentric outer layers of wood provides a non-conformity so striking that the year when the tilting occurred can be recognized almost at first glance. This same response is evident regardless of the tilting agent, and may be used to date landslides [LANGENHEIM, 1949], windstorms [PILLOW, 1931], and floods accurately. In addition, the pressure of glacier ice against the trunk may leave a scar similar to a fire scar (see Fig. 1, I) which may be readily detected in the cross section. Occasionally too, the whole upper part of a tree trunk or a large lower branch is broken off by the pressure of the ice and in such cases a dormant bud may grow out of the remaining basal part as soon as the ice begins to recede, and may develop into an erect daughter tree (see Fig. 1, J), the number of whose growth layers represents quite accurately the number of years since recession began. Tilting at trimline by windthrow must not be confused with tilting by ice.

Change in growth rate of erect trees indicating changed environment--In some cases an erect tree may have the lower part of its trunk buried by till or outwash and the date of that event may be evident in a sudden and prolonged change in ring growth rate in spite of continued erect position and concentric wood production throughout its lifetime. The year when a volcanic ash blanket was deposited on a region may be ascertained in the same way, and thereafter the presence or absence of that ash layer on a given moraine will help greatly in working out the glacier history. A period when glacier ice was very close to a tree may also be evident in the growth layer pattern, through marked reduction in the thickness of the rings produced when the ice was nearby even though the ice did not actually touch the tree [Mathews, 1949, personal communication].

Methods

Collecting--The study of tree ring records requires some method of collecting a sample from

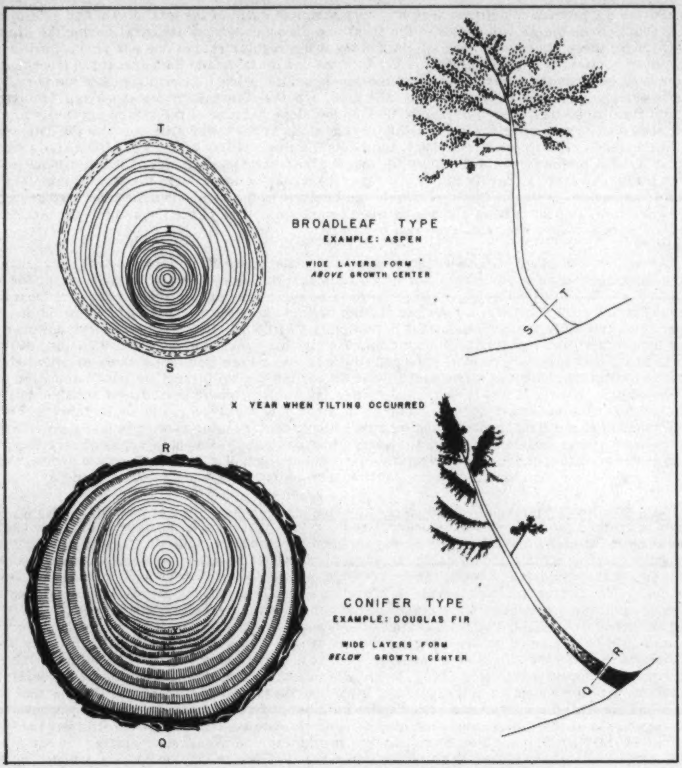
T
X
S
BROADLEAF TYPE
EXAMPLE: ASPEN
WIDE LAYERS FORM *ABOVE* GROWTH CENTER
S
T
X YEAR WHEN TILTING OCCURRED
R
Q
CONIFER TYPE
EXAMPLE: DOUGLAS FIR
WIDE LAYERS FORM *BELOW* GROWTH CENTER
R
Q

Fig. 2--Responses of conifer and broadleaf types of trees to tilting which occurred ten years before they were cut down

the tree in question. The easiest method, which also produces least injury to the tree, is the removal of a core about the size of a lead pencil, with a tool called the Swedish increment borer. It is a rather expensive and delicate instrument that requires careful use and thorough cleaning and oiling after each day's work. United States Forest Service personnel have been exceedingly cooperative in lending these borers to research workers. The other type of sampling tool is a coarse-toothed (six or eight teeth to the inch) carpenter's crosscut hand saw, or a four-foot, or longer, two-man saw; these of course, should be properly filed and set for the type of wood to be cut. For the study of timberline trees, a complete cross-section about one-half inch thick is far more useful than a core obtained with a borer, since the growth layers of timberline trees are so exceedingly thin and indistinct along certain radii that a core would be practically useless. In the complete section the center of growth is bound to be present, whereas the investigator is lucky to hit the earliest growth ring with a borer. The cores, once obtained, are very delicate and breakable, and they must be placed individually in special containers, for example plastic or metal tubes just slightly larger than the core and corked at both ends, as soon as collected so that they will remain in good condition until a careful study can be made. A few flakes of naphthalene placed in the tube prevent growth of fungi. After all factors

are considered, the complete cross section sample, taken from the very base of the stem where the trunk has most rings, is most satisfactory. Since the stem base, however, may sometimes be a foot or so below the soil surface, excavation with a shovel may be necessary.

Since most of this type of work may be carried on in National Forests and National Parks, written permission to cut occasional trees should be obtained in advance. Even after permission has been obtained, careful selection of trees should be made to avoid impairment of scenic values. In some cases a horizontal limb growing out of the trunk just above the soil surface will provide an adequate substitute for the cross section of the main trunk, and it will be easier to cut, but the rings will be much narrower and harder to count.

Mention has already been made of the usefulness of aerial photographs in this type of work and every effort should be made to obtain these before beginning the field work. Stereopairs taken vertically or as low obliques by simply snapping two photographs of the same terrain from two different positions as the airplane moves along its course, will be most satisfactory because these will allow stereoscopic study of even the tiny morainic ridges which sometimes are so difficult to see on the ground and especially difficult to map. The photographs should include the whole lower part of the glacier and the forested area beyond the terminus so that correlation of lateral and end moraines may be worked out. One set of these photographs provided with tracing film overlays should be taken into the field when the wood samples are collected so that the exact position of each tree sampled can be immediately indicated on the photo overlay.

The trunk cross sections should be carefully labeled when collected, on the lower cut surface giving location of the tree on the photo, height of the cut above the original stem base, amount and character of the material excavated from about the trunk base, nature of the forest floor and soil profile, whether or not the trunk was leaning and the direction of the lean, the date when the sample was collected, and the kind of tree.

Preparation and study of the sample-- The cross section samples should be dried and then the upper cut surface polished with sandpaper. Though various grades can be used in the preliminary smoothing, nothing coarser than 6/0 grade should be used in the final polishing; in material polished in this way, the individual cells can be easily recognized, with proper magnification. A sanding machine, though not essential, saves much time and hand labor; the orbital and back-and-forth action machines manufactured by the Sterling Products Company of Chicago are most satisfactory. Once polished, the annual rings may be found to be so extremely narrow, 200 to the inch perhaps, that a strong magnifying lens (five to 40 power) will be necessary for making the count. The Master Magnifier Set No. 44, sold by the R. P. Cargille Company, 118 Liberty Street, New York, is well suited for this work. In conifer trees each ring will be seen to consist of two parts, an inner light colored soft zone which forms in the spring, and an outer dark colored hard zone which forms during the summer (see Fig. 1, extreme left); the two zones together, of course, represent one year's growth. This difference in color between the adjacent parts of rings makes it relatively easy to count them in most conifers. The growth layers of some broadleaf trees are almost as easily counted, but in many others the color contrast between adjacent rings is so slight that counting is very difficult indeed. Delicate pins are used to keep one's place as one counts from edge to center. Use of a hand tally register and a duplicate count for checking improve accuracy of the results.

Recording the data-- As soon as the age of a tree has been worked out from the wood sample, the date (for example, 1560 A.D.) of the innermost ring counted, and the height of the sample above the stem base if it could not be obtained from the actual base, or an index letter or number that can be referred to in the field notes, should be recorded on the tracing film overlay on the aerial photograph. When all the data have been recorded the work of interpretation can be begun. The number of years required for a tree seedling to attain a given height above the soil surface is one of the unknowns involved in this type of research and a great deal of detailed study will have to be done before estimates can be made with much assurance of accuracy; samples of the wood should therefore be taken from the true stem base wherever possible.

Analysis service provided

Cores and sections carefully labeled and accompanied by field data and photographs may be sent to the writer for analysis if desired, and he will, as time allows, prepare a brief report of results for the collector. Copies of these reports will be transmitted to the Chairman of the Committee on Glaciers for inclusion in his annual reports.

Acknowledgments--I am particularly grateful to Kenneth N. Phillips and to my wife for their devoted help in the field, in the collecting of material whereby these techniques have been developed. I am grateful also to William S. Cooper, William O. Field, Jr., and to the late François E. Matthes for their continued encouragement in this line of investigation, and to the University of Minnesota Graduate School for financial aid.

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CRITICAL ESCAPE VELOCITY FOR A POROUS MEDIUM WITH A FREE SURFACE

Karl S. Pister

Abstract--An equation for the critical vertical escape velocity causing instability or a "quick" condition in a porous medium with a free surface is developed in terms of a critical resistance coefficient. The suitability of describing a porous medium by its porosity and a statistical size parameter based upon geometric mean particle size and geometric standard deviation is indicated. Experimental data are presented.

Introduction--The problems of flow of fluids in porous media are indeed manifold. This paper deals with a limited phase of the general problem, the development of an expression for the vertical escape velocity which produces instability or a "quick" condition in an unconsolidated medium. The parameters used to describe the medium and procedure followed are applicable, however, to any type of problem involving flow in porous media.

Resistance of a particle in a fluid stream--An isolated particle in a vertical fluid stream will be displaced in the direction of flow when the forces of flow exceed the immersed weight of the particle. The forces acting upon the particle consist of a surface drag dependent upon the surface area of the particle exposed to the fluid and a form drag dependent upon particle shape and resulting from the differential pressure on the approaching and receding faces of the particle. The classical treatment of this phenomenon indicates that the resistance of such a particle may be expressed by the general relation $F = CA\rho V^2/2$, where F is the resisting force of the particle, A the projected area of the particle normal to flow, ρ the fluid density, V the velocity of flow, and C the coefficient of resistance which is a function of Reynolds number and particle shape. It can be seen that if the velocity of flow for a given condition is sufficient to cause the resistance F to exceed the immersed weight of the particle, flotation will occur. For a sphere it can be shown that this condition is met wher $V^2 = C(\gamma_s - 1)d$, where γ_s is the specific gravity of the particle. It is further evident that a series of particles (so spaced to prevent mutual interference) of similar shape, differing only in size, under the same flow conditions would experience flotation progressively as the velocity increased. Likewise, the coefficient of a single particle is influenced by the surface area of the particle and its area-volume ratio. Under similar conditions of flow an irregular particle of given size will show greater resistance to flow than a spherical particle of the same average diameter inasmuch as its area-volume ratio is larger than that of the sphere.

Extension of theory to unconsolidated media--A consideration of the resistance of a medium requires first the inclusion of a factor to account for the mutual interference of the particles. For a group of isolated particles, there is no appreciable interference of the flow pattern. However, when a group of particles is aggregated to comprise a medium, there is no doubt as to the importance of the interference of the particles with the flow pattern. It is apparent, that, depending upon the arrangement of particles, restriction of the flow will occur in some areas with consolidation in others. That is, the arrangement of particles in a medium is such that an interconnecting channel through which flow occurs is of variable cross-section. In such a channel the microscopic velocity would increase and decrease to compensate for this change in area to maintain continuity of flow. It is evident that in porous media comprised of particles of varying size, the smallest particles will tend to be displaced first, with a subsequent movement of larger ones as the velocity is increased. Thus, the importance of frictional forces can be seen. The forces of flow must overcome these forces in addition to the immersed weight of the particles to cause flotation. The difficulty involved in the proper selection of a term to extend the theory for singular particles to medium resistance is apparent. Such a factor would be a function of Reynolds number, the size, shape, and distribution of the particles, and the porosity of the medium. The character of the medium would, of course, depend upon the latter factors which in turn govern the effects of mutual interference and frictional forces. The equation representing the condition for flotation of the medium would be of the form

$$V^2 = C'(\gamma_s - 1)d \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where C′ is dependent upon the factors mentioned, d is some parameter of particle size, shape, and distribution, and V is the macroscopic or average velocity per unit area of cross-section.

__Characteristics of porous media__--The porosity of a medium, a measure of the volume of the flow channels compared to the total volume of the mass, in itself is not a sufficient criterion for exact definition of the medium. The porosity of a medium is dependent upon the size distribution, the shape characteristics of the individual particles comprising the mass, and their degree of compaction. It is evident that two entirely different media (in shape and size of particles) might be compacted to comparable porosity. However, when used in conjunction with values of size and shape for the particles, the porosity is a satisfactory parameter for comparison of different media.

Particle size is a three-dimensional term implying volume and can be described by a diametral term only if that term infers volume. Particulate media are not defined by a single mean value such, for example, as the mean diameter. Parameters may be employed, however, as a function of some particle diameter and its numerical frequency of occurrence. Non-uniform particulate materials, such as sand produced by natural means, have size-frequency distribution curves which have the shape of the logarithmic probability curve. That is, the size distribution of natural sands approaches geometric normality. This curve may be defined by the statistical parameters, the geometric mean diameter, and the geometric standard deviation. Diametral terms describing the particles can be determined from the logarithmic probability curve. It should be noted that, strictly speaking, the probability curve is dependent upon the numerical frequency of occurrence of particles of a certain size. In determining the frequency curves by ordinary sieve analysis the percentage weight of particles of given size is determined. It has been shown, however, [HATCH and CHOATE, 1929] that the weight percentage is a direct function of the numerical frequency of occurrence. Inasmuch as the size frequency curve follows the logarithmic probability law, the distribution curves in terms of surface area, weight, or any other functions of size and count will have the same form. Since the distribution of sieve sizes is also geometric, it follows that the best parametric representation of sand size and distribution would be given by the geometric mean diameter and geometric standard deviation, determined by standard sieve analysis. However, any attempt to select a parameter for size is at best arbitrary, since in actuality the flow occurs around the particles and not through them. Hence, the diametral term in effect relates the size of the flow channels surrounding the particles to the particle size causing the flow resistance, no absolute measurement of the flow channels being possible. This brings to light the importance of the concept of specific surface of the particles, or the average surface area per unit volume. The importance of such a concept is emphasized by the manner of resistance of a porous medium, that is, the large percentage of the resistance that can be attributed to the surface drag of the particles on the fluid.

If the assumption that the surface of a single particle is a function of the square of the diameter and the volume a function of the diameter cubed is made, the diameter of a particle of average surface area per unit volume of the mass can be evaluated from the normal probability curve. The mathematical development of this expression has been given by [HATCH, 1933]. The resulting diameter

$$\log d = \log M' - 1.1513 \log^2 \sigma \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where M' is the geometric mean diameter and σ is the geometric standard deviation both determined by sieve analysis. It is well to note that this expression does not include the shape factor which is present in the development mentioned and is actually necessary for complete description of particle size. On the basis of grain photographs the shape factor was assumed to be constant for the sands used, and for this reason was omitted from the size term in this investigation.

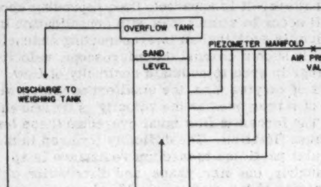

Fig. 1--Schematic diagram of apparatus

__Experimental apparatus__--To check the theoretical relationships expressed in (1), an experimental apparatus was constructed for measurement of pressure drop and flow rate in a tower containing sand particles (see Fig. 1). Water was circulated through the system from the bottom of the tower. The flow tower was fabricated from Lucite of six-inch interval diameter, approximately five feet high. An overflow reservoir on the top of the tower was drained by a pipe which discharged into a weighing tank. The bottom of the tower was sealed by a screened, bolted flange which could be removed to facilitate changing sands. Pressure taps were located in pairs, diametrically opposed, at six-inch intervals over a total distance of 30 inches. The taps were in turn connected to piezometers which were manifolded at the top and connected to a valve through which air pressure could be applied

Table 1--Properties of materials tested

Item	Sand		
	No. 2	No. 4	No. 6
Specific gravity	2.62	2.61	2.60
Geometric mean diameter, ft	0.00141	0.00305	0.00425
Geometric standard deviation	0.53	0.77	0.62
Diameter of particle of average specific surface, ft	0.00118	0.00295	0.00393

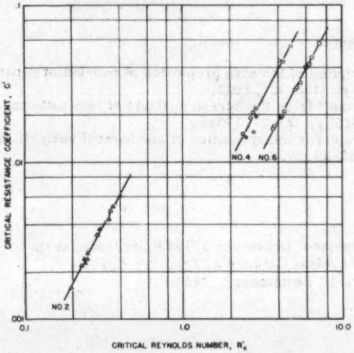

Fig. 2--Relationship of C' to Reynolds Number

to control the height of rise of the columns.

Materials tested--The materials used in this investigation consisted of three different size distributions of Monterey beach sand. The physical properties of the materials are given in Table 1. The statistical parameters of geometric mean size and standard geometric deviation were obtained from a logarithmic probability plot of size distribution [OTTO, 1939].

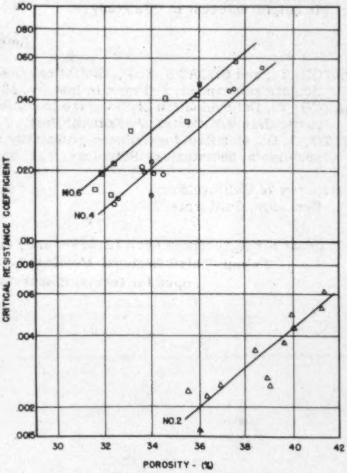

Fig. 3--Effect of porosity on critical resistance coefficient

Experimental procedure--Prior to packing the tower the sand was submerged. It was then placed in the tower under water in two- to three-inch layers and rodded uniformly. Use of this method of placement decreased the opportunity for air to collect in the pore spaces. The possibility of increased sorting of the sand mass by use of this method was considered, but the uniformity of the sand as determined by actual inspection as well as the uniformity of the head loss measurements seemed to justify this method of packing. Void percentages in the sand mass were calculated from the weight and volume of the material in place and its specific gravity.

For a particular test various rates of flow were used, starting at very low rates and gradually increasing. For each rate of flow the quantity and head loss was observed. This procedure was repeated until the mass was finally displaced in the direction of flow.

Analysis of data--To investigate the validity of (1) the experimental data were used to plot values of the resistance coefficient, C'. Figure 2 shows the variation of the resistance coefficient with the critical Reynolds Number at the velocity of flotation. The effect of initial porosity of the medium upon the coefficient is shown in Figure 3. On the basis of the limited data obtained it seems that the resistance of a porous medium to flow is analogous to that of a particle in a fluid stream and that a critical coefficient can be determined, from which the critical escape velocity can be found.

By plotting the relationship of the velocity to the head loss (not shown) it was found that for all escape velocities the flow was in the laminar regime. The use of the diameter of particle of average specific surface is particularly significant inasmuch as viscous resistance depends upon surface drag phenomena. It would seem that the use of this parameter, incorporating both size and size distribution, along with the porosity, might well be used in any problem dealing with viscous flow in porous media. The logarithmic probability plot of size distribution affords a simple means of determining this size parameter. It is well to note, however, that to extend this application to media comprised of particles of different shape characteristics it is necessary to include a shape factor term in the size parameter.

Acknowledgment--The author is indebted to J. W. Johnson, University of California, Berkeley, for his helpful interest in this study.

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A METHOD OF EVALUATING THE HYDROLOGIC EFFECTS OF LAND USE ON LARGE WATERSHEDS

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(Publication approved by Director, Northeastern Forest Experiment Station)

Abstract--This paper presents a method for subdividing the total flood hydrograph into separate hydrographs for surface, subsurface, and ground-water runoff. A unit hydrograph is derived by considering surface and subsurface runoff contributing simultaneously by unit time periods. The total flood hydrograph as modified by a land-use program is computed by using the above derived unit hydrograph, ground-water relations, and changes in land use.

Introduction--Hydrologic evaluation of land-use and management practices as recommended in the flood-control surveys of the United States Department of Agriculture requires new techniques and methods of approach. Three separate and distinct types of runoff must be considered, namely surface, subsurface, and ground-water, in order to make a complete analysis of the hydrograph.

The study presented herein is limited to one watershed - the Baker River in the Merrimack watershed. The watershed has a drainage area of 143 sq mi, and includes a portion of the White Mountains of New Hampshire. The topography varies from rolling to very steep slopes and is conducive to rapid runoff. This watershed has a satisfactory coverage of the United States Weather Bureau nonrecording and recording rainfall gages, and about 20 years of stream-gaging record. The watershed considered is located above the United States Geological Survey recording stream gage at Rumney, New Hampshire.

A detailed study on this watershed indicates that surface runoff represents 17 per cent of the total annual runoff, subsurface runoff 44 per cent, and ground-water runoff 39 per cent. An examination of runoff data, which was obtained by the Soil Conservation Service on small plots located in the Northeast, indicates that the annual surface runoff from a large watershed that has an average land-use pattern and condition should average between 15 and 25 per cent of total runoff.

Ground-water analysis--The complete discharge record at Rumney was plotted in water years for the period November 1928 to September 1946 (see Fig. 1). Discharge was plotted on a logarithmic scale to emphasize the low flows. Each day on which rainfall occurred was shaded on the bottom of the graph and shown as being either less than or more than 0.1 inch. If no rain or snow melt occurred for five consecutive days, the succeeding daily dishcarges were considered as entirely sustained by ground-water. HORTON'S [1935] method for analyzing stream flow was very helpful in separating ground water from the total flow. The shaded portions directly beneath the hydrograph indicate periods that were designated as being sustained entirely by ground-water runoff. Ground-water discharges were grouped separately by months and the successive differences in consecutive daily values were computed.

In order to evaluate the daily rate of change in ground-water depletion, these successive differences in mean daily discharge were plotted against the corresponding discharges (see Fig. 2). Those values were plotted for each month that had sufficient data to warrant separate analysis. A weighted average curve was drawn through the plotted points. These monthly curves, when p plotted on one graph, fell into a family of curves with their average monthly evapotranspiration losses as the parametric variable. No attempt was made, however, to correlate these monthly curves with their respective evapotranspiration losses. Thus, May and October, among the months shown, have the greatest discharge because evapotranspiration is then at a minimum, and July and August have the minimum discharge because evapotranspiration is maximum.

Ground-water depletion curves were computed for each month by subtracting the successive difference in daily discharge from the highest value of discharge shown on the graph (see Fig. 2). and repeating the process for about 60 succeeding days. The computed daily values were plotted against time to obtain a ground-water depletion curve for each month (see Fig. 3). Ground-water

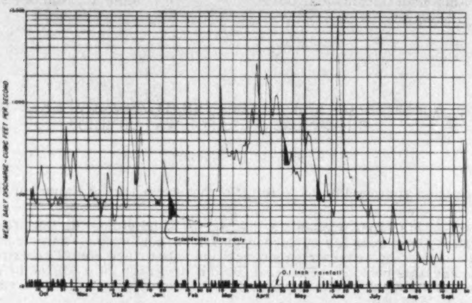

Fig. 1--Selection of ground-water discharge from inspection of rainfall data and annual discharge hydrograph, 1941-1942

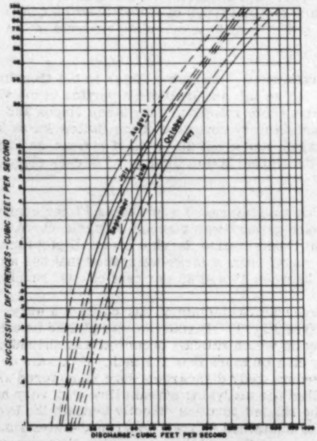

Fig. 2--Average relation between successive differences in mean daily discharge to the mean daily discharge

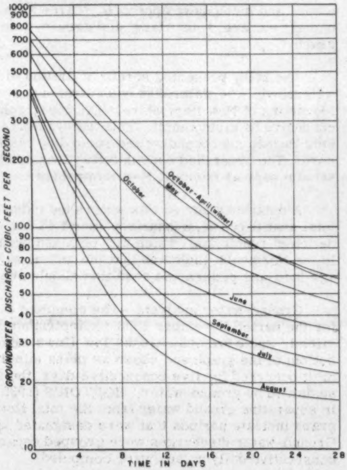

Fig. 3--Ground-water depletion curves

storage-discharge curves (see Fig. 4) were computed for each month by integrating the ground-water depletion curve above the minimum discharge shown on the graph (see Fig. 3). All ground-water storage-discharge curves were extrapolated to the same maximum discharge. Ground-water depletion and storage-discharge curves have been contructed previously on other watersheds by HORTON [1931], BARNES [1939], SNYDER [1939], and LANGBEIN and others [1947].

Ground-water hydrograph for June 1942 flood--The observed flood hydrograph was plotted with ordinates of discharge exaggerated to facilitate determination of the ground-water hydrograph (see Fig. 5). A template was made of the June ground-water depletion curve according to the scales of the hydrograph. Inspection of the hydrograph disclosed that on the morning of June 13 discharge consisted only on ground water. The template was placed on the graph tangent to the hydrograph on the morning of June 13. The ground-water depletion curve was then drawn along

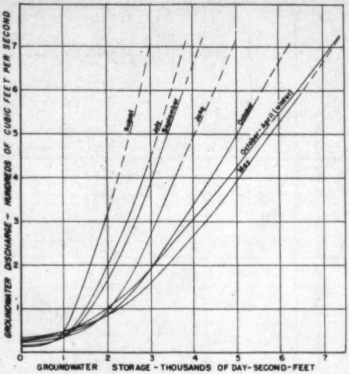

Fig. 4--Ground-water storage-discharge curves

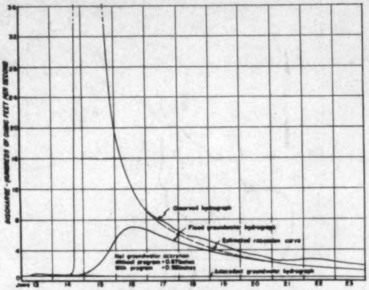

Fig. 5--Ground-water accretion for June 1942 storm

the template on the graph to delineate what the hydrograph would have been if the storm of June 14-15, 1942, had not occurred.

Subsequent rainfall that occurred during the period June 16-25 prevented the hydrograph from returning to ground-water flow. The June ground-water template was again placed on the graph in such a position as to exclude from the hydrograph any runoff caused by the subsequent rainfall. The ground-water hydrograph was then constructed along the template and extended towards the time of peak discharge of the total hydrograph. By assuming the peak ground-water discharge and that this peak occurred about one day after the peak of the observed hydrograph, the ground-water hydrograph was completed by drawing a smooth transition from the peak forward to the inflection of the depletion curve and a curve from the peak back to the start of the flood with the characteristic shape of the rise of the unit hydrograph. BRATER [1939] used a similar basis for constructing the ground-water hydrograph.

The volume of ground-water runoff caused by the June 1942 flood was determined as the volumetric difference between the antecedent and flood ground-water hydrographs. One part of it was obtained by measuring the area on the graph between these two ground-water hydrographs. The other part of it was obtained by reading from the July ground-water storage-discharge curve, the storage in cfs-days corresponding to the discharge of each ground-water hydrograph at midnight on June 26 and obtaining the difference in storage. These two values indicated a net ground-water accretion of 0.87 inch due to the June 1942 flood.

The ground-water hydrograph was subtracted from the total hydrograph to obtain the hydrograph for surface and subsurface runoff.

Surface runoff hydrograph for June 1942 flood--The average rainfall over the watershed for the June 1942 storm was determined from an isohyetal map (see Fig. 6). The rainfall intensities were determined from duplicates of the original charts for the United States Weather Bureau recording rain gage at Warren, New Hampshire. This gage is located in the north-central portion of the watershed. The total recorded rainfall at this station (7.57 inches) was nearly equal to the average rainfall for the watershed. Rainfall intensities were selected from the charts for 5-, 10-, and 15-min periods dependent upon the steadiness of the intensity. These intensities were prorated to the average watershed rainfall.

A land-use field inventory of the soil-cover complexes was made in connection with a flood-control survey report for the Merrimack watershed. Infiltration rates for these soil-cover complexes were based on infiltrometer runs made for the Connecticut Watershed flood control survey. The influence of vegetation on runoff, based on nine years of infiltrometer research, was presented by ROWE [1948]. Rainfall excess was computed by applying the infiltration rate for each soil-cover complex to the rainfall intensities. The total weighted value of the rainfall excess represents the amount of surface runoff, 2.22 inches.

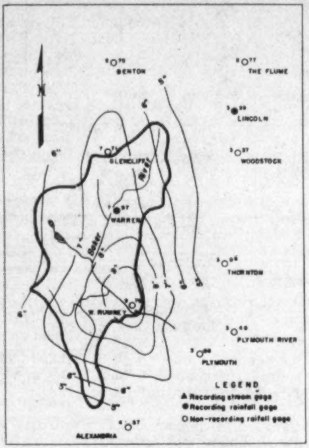

Fig. 6--Isohetal map of the storm of June 14-15, 1942

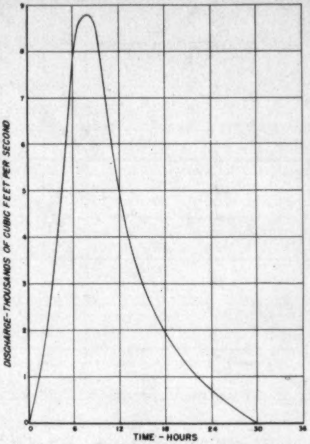

Fig. 7--One-hour unit hydrograph

To obtain the surface runoff hydrograph, it was necessary to derive a unit hydrograph (see Fig. 7). A unit hydrograph was drawn from an analysis of the observed runoff hydrograph and the drainage basin characteristics as defined by SNYDER [1938]. It was assumed that its time of concentration would be equal to about the time from the center of mass of rainfall to the peak of the total hydrograph, which was about eight hours. Soil-moisture field investigations by MOREY [1941] revealed that the moisture in the soil profile returned to field capacity in about five days after significant rainfall. Therefore, it was logical to conclude that subsurface runoff must provide most of the discharge during the lower part of the recession curve. It was therefore decided that the unit hydrograph should have a base of about 30 hr. The shape of the trial unit hydrograph was made to conform to the characteristic shape of unit hydrographs. The surface-runoff hydrograph was computed by applying the weighted rainfall excess value to the unit hydrograph values by hourly periods. One adjustment was necessary in the shape of the unit hydrograph to make the peak of the surface-runoff hydrograph conform reasonably to time of peak discharge of the total hydrograph. This surface-runoff hydrograph was subtracted from the combined hydrograph of surface and subsurface runoff in order to obtain the subsurface hydrograph.

Subsurface runoff hydrograph for the June 1942 flood--The volume of subsurface runoff was determined by measuring the area of its hydrograph and converting it to inches of runoff. Subsurface runoff [BRATER and HURSH, 1941] is considered to occur usually either as lateral movement in the upper horizons of the soil profile, eventually seeping out on the surface of the ground, or as outflow in the form of wet-weather springs from temporarily perched water tables. The rate of contribution of subsurface runoff varies with the excess of soil-moisture storage above field capacity and was determined by a rating curve established by trial and error (see Fig. 8). The first subsurface contribution rating curve was based on field measurements of soil moisture in northern New England, which indicated the daily rate of change in soil moisture returning to field capacity.

In making the land-use inventory, special consideration was given to the portion of the total watershed area that would contribute to subsurface runoff. This area was classified separately into soil-cover complexes. The rainfall excess for this subsurface contributing area was computed separately. The weighted average rainfall excess was then subtracted from the corresponding average basin rainfall amount to obtain the volume of water infiltrated into the soil by hourly periods.

Evapotranspiration losses from the moisture in the soil profile are responsible for the soil-

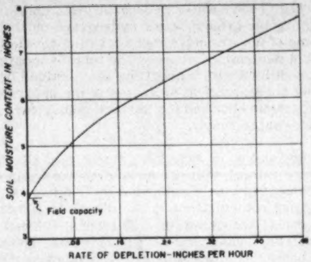

Fig. 8--Rating curve for subsurface runoff

moisture deficiency usually existing at the beginning of a storm. The deficiency of soil moisture below field capacity at the beginning of the storm was determined by evaluating each factor that had affected the amount of moisture in the soil profile since it was last at field capacity. This method was developed by LOWRY and JOHNSON [1941]. The total rainfall, runoff, and ground-water accretion due to this rainfall, and the evapotranspiration losses, were determined for this period. These values were added algebraically to obtain the soil-moisture deficiency.

The infiltrated water was routed through the soil-moisture storage by hourly periods, using the above trial subsurface-contribution rating curve. Subsurface runoff did not occur until the soil-moisture storage exceeded the value of field capacity. The routing was continued until the soil moisture had returned to field capacity. These computed subsurface contribution values were prorated to the volume of subsurface runoff obtained from the above subsurface-runoff hydrograph. This was done on the basis that the ratio of these values would represent that part of the watershed contributing to subsurface runoff. These rates of subsurface contribution to the hydrograph are equivalent to rates of surface runoff at the time flow emerges to the surface from its underground travel. They are applicable to the unit hydrograph at the time they become surface flow. It is realized that subsurface flow, returned to channelized surface flow, would have a shorter time of concentration than the average surface runoff, but the difference can be disregarded since it would average about five to ten minutes. This difference is due to elimination of time of overland flow required for surface runoff to reach stream channels.

The subsurface-runoff hydrograph was obtained by applying the above rates of contribution to the unit hydrograph by hourly periods. The rating curve for subsurface runoff contribution was adjusted by successive trials until the subsurface-runoff hydrograph was satisfactorily reproduced. The combined hydrograph for surface and subsurface runoff was reproduced by adding their respective hydrographs. The reproduction was considered satisfactory (see Fig. 9).

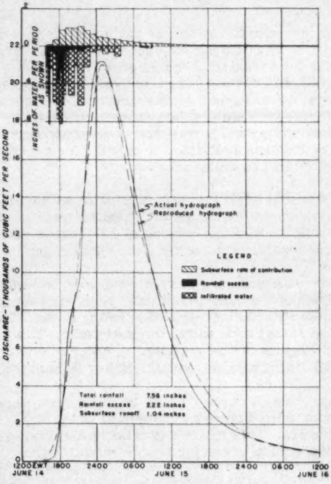

Fig. 9--Reproduction of June 1942 hydrograph

June 1942 flood hydrograph with a modified land-use program--A modified land-use program would create higher infiltration rates on a greater proportion of the area of the soil-cover complexes. Therefore, the weighted rainfall excess was recomputed by applying the infiltration rates of the changed areal extent of the soil-cover complexes to the identical rainfall intensities used above. The surface-runoff hydrograph with a program was then computed by applying the new weighted rainfall excess to the unit hydrograph (see Fig. 10).

In a similar manner the rainfall excess was recomputed for the area contributing to subsurface runoff. This weighted rainfall excess was then subtracted from the corresponding average basin rainfall values to determine the water infiltrating into the soil by hourly periods. After careful deliberation it was decided that the same proportion of the volume of infiltrated water would become subsurface runoff and net ground-water accretion as determined for conditions without a program. The subsurface-runoff hydrograph was computed by routing hourly amounts of infiltrated water through the soil-moisture storage by using the rating curve for subsurface contribution and applying these values to the unit hydrograph. This gave an increase in volume of subsurface runoff with a modified program.

The ground-water hydrograph was obtained by adjusting the ground-water hydrograph until the volume of net ground-water accretion equaled the amount determined above. The total hydrograph for conditions with a program was obtained by adding corresponding ordinates of the separate hydrographs obtained for surface, subsurface, and ground-water runoff.

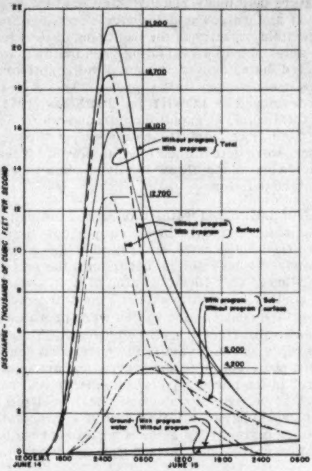

Fig. 10--Surface, subsurface, ground-water, and total hydrographs for the June 1942 flood with and without a modified land-use program

Accounting of June 1942 storm rainfall--The average rainfall that occurred over the basin during the June 1942 storm amounted to 7.56 inches. In the above computations it was determined that surface runoff accounted for 2.22 inches, subsurface runoff 1.04 inches, and net ground-water runoff 0.87 inch. The soil-moisture deficiency at the beginning of the storm amounted to 0.39 inch.

In order to estimate what happened to the balance of the storm rainfall, the ground-water storage-discharge curves determined in the beginning were reexamined. It is commonly accepted that the ground-water discharge at any time is a function of the total ground-water storage at that time. CROFT [1948] determined on the Farmington Watershed in Utah that, because of evapotranspiration losses, the stream flow fluctuated diurnally, with temporary weather changes and with seasonal weather changes. It was determined that for a given storage the ground-water discharge varied inversely to the evapotranspiration losses. It seemed obvious that the ground-water discharge at any time would depend upon what the evapotranspiration losses were at that time and the total amount of ground-water storage.

In the ground-water storage-discharge curves for any month, the author has acknowledged only the actual runoff that occurred. Obviously, there must be an additional amount in storage to take care of evapotranspiration losses for that month. In order to estimate the amount, the ground-water storage corresponding to the maximum discharge of the June 1942 ground-water hydrograph was read from the June and October storage-discharge curves. Since evapotranspiration losses also occur during October, the difference in storage between these two curves was increased in such a way as to eliminate the effect of evapotranspiration losses. It was thus determined that 1.46 inches of ground-water accretion occurred during the June 1942 flood to provide for eventual evapotranspiration losses. This leaves a balance of 1.58 inches unaccounted for.

The author has progressively accounted for the storm rainfall that was dissipated as surface runoff, subsurface runoff, or ground-water runoff, or was held in storage for eventual runoff and evapotranspiration losses. It is conceivable that the unaccounted-for balance of 1.58 inches may have gone into deep seepage below the permanent ground-water table of the Baker Watershed.

Flood hydrograph of September 1938--An analysis was made of the hurricane flood of September 1938 by using the methods developed for the analysis of the June 1942 flood. No change or adjustment was made in either the unit hydrograph or the subsurface contribution rating curve. There was, unfortunately, no recording rain gage in operation at that time within the watershed. The September 1938 Storm Study (NA 2-2) by the Corps of Engineers was reviewed in order to obtain the best possible mass rainfall curve for average total storm rainfall over the Baker Watershed.

Hourly values of rainfall were read from the mass rainfall curve. These hourly values were then broken down into 5-, 15-, and 30-min intensities by using Figure 2, Chapter 21 of the September 1942 Engineering Manual of the Corps of Engineers. This figure indicates on the average what 5-, 15-, and 30-min rainfall intensities can be expected to occur for hourly rainfall values up to 4.5 inches.

The reproduction of the September 1938 flood hydrograph (see Fig. 11) indicates that the

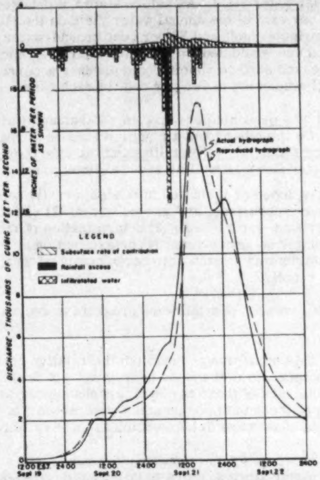

Fig. 11--Reproduction of September 1938 hydrograph

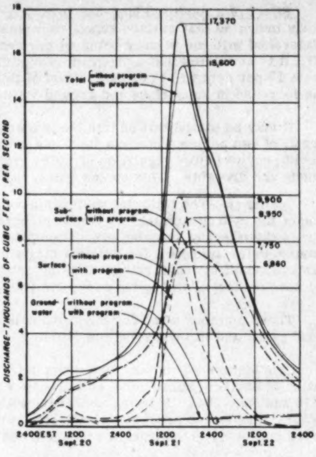

Fig. 12--Surface, subsurface, ground-water, and total hydrographs for flood of September 1938 with and without a modified land-use program

author's mass rainfall curve analysis had too high a rainfall for period 07h00m-10h00m EST, and too low a rainfall for period 16h00m-19h00m EST September 21. The mass rainfall curve could have been reexamined and revised to obtain a better reproduction of the flood hydrograph. The reproduction as shown was obtained by applying the methods used in the analysis of the June 1942 flood hydrograph without any changes or adjustments.

Flood hydrograph of September 1938 with a modified land-use program--The surface, subsurface, ground-water, and total hydrographs (see Fig. 12) were determined for the September 1938 storm with a modified land-use program by using the identical methods established in the June 1942 study.

Comparison of the flood hydrographs of June 1942 and September 1938--Since very little rainfall occurred during 17 days preceding the flood of June 1942, the soil-moisture deficiency was considerable and the stream flow was entirely from ground water. Frequent rainfall preceding the September 1938 flood resulted in the soil moisture being above field capacity and the stream flow consisted of both subsurface and ground-water runoff. These antecedent conditions in combination with high-intensity, short-period rainfall for the storm of June 1942 and relatively low-intensity, long-period rainfall for the storm of September 1938 determined relative amounts of surface and subsurface runoff in the hydrographs.

In the flood hydrograph of September 1938 the peak discharge of surface and subsurface were about equal, whereas for June 1942 the surface runoff was about three times the subsurface. The comparison of these floods indicates the effectiveness of a modified land-use program in reducing flood peaks for different types of storms and antecedent conditions.

Flood reductions on large watersheds--The methods presented herein make possible the determination of flood reductions attributable to a modified land-use program on a large watershed. The flood hydrograph, as modified by a change in land use, can be determined for an area of any size for which the unit-hydrograph theory is applicable. Flood hydrographs, based on unit hydrographs and for subdivided areas, can be routed downstream through valley storage to determine flood reductions for the larger watersheds.

Effect of a modified land-use program on annual water yield--As before stated, a detailed study indicated that surface runoff represented 17 per cent of the annual water yield on the Baker Watershed with the balance being 44 per cent subsurface runoff and 39 per cent ground-water runoff. It is estimated that a program of modified land use would reduce the annual surface runoff from 17 per cent to 11 per cent. Part of this decreased surface runoff would produce a corresponding increase in subsurface and ground-water runoff amounting to two per cent in each case.

It may be stated that on this basis there would be a probable decrease in total annual water runoff of two per cent due to a land-use program. On the other hand a modified land-use program would provide better regulation of water yield during the entire year, mitigating the effects of floods and droughts. This means increased low-water flows as well as reduced flood peaks.

Summary--The following methods have been developed or indicated in this paper: (1) separation of the hydrograph into its components of surface, subsurface, and ground water; (2) estimation of the effect of riparian evapotranspiration of ground-water runoff; (3) determination of the ground-water accretion for either a single storm or for an entire year; (4) determination of the surface runoff hydrograph based on the relative contribution of each soil-cover complex; and (5) development of the rating curve for subsurface runoff.

These methods when combined indicate the effectiveness of a land-use program in decreasing flood peaks and in increasing low flows.

Conclusions--The most important objective of this study was to establish the relative contribution of surface, subsurface, and ground-water components to the flood hydrographs of September 1938 and June 1942. It is realized that, while the analyses of these two hydrographs appear satisfactory, conclusive proof rests with the application of these methods on other watersheds. It is hoped that other investigators will use these methods elsewhere to help establish their validity.

While the use of average infiltration rates as determined from infiltrometer runs gives a reasonable approximation of surface runoff during major storms, there is still considerable opportunity for improving the computation of surface runoff. It is believed that the method of HOLTAN [1945] for computing infiltration curves based on analysis of actual storms on very small watersheds, combined with the method of SCHIFF and DREIBELBIS [1949] for determining the permeability of the soil profile, offer the best possibilities of improvement in computing surface runoff. As methods are improved for computing any runoff component, they can easily be substituted within the complete method described herein.

The determination of the hydrologic effect of land use and management on flood runoff from large watersheds is a controversial matter. As yet no complete modified land-use program has been installed on any large watershed so that its effectiveness could be measured. A great deal of work has been done on small watersheds but it is difficult to extrapolate such data to large watersheds. Unless there is a major change in land use, it is difficult to compare flood peaks for separate storms on a large watershed because each storm has different antecedent rainfall conditions, rainfall intensities, total rainfall, and rainfall depth-area relations. The effect of land use on flood runoff can best be demonstrated by methods of hydrologic analysis that include not only these variables but also the relative contribution of surface, subsurface, and ground-water flows

The aim of this paper is not only to indicate how a land-use program can effectively decrease flood peaks and increase low flows, but also to emphasize that land use must be thoroughly considered in determining the flood potential of a watershed for the hydrologic design of culverts, bridges, and spillways.

Acknowledgments--Grateful acknowledgment is made to Arthur Bevan for guidance and inspiration and to Lemuel E. Miller and John B. Cavallero for technical assistance.

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DEFORMATION IN THE PEACH BOTTOM SYNCLINE

S. L. Agron

Abstract--Results of a detailed study of the deformation in the Peach Bottom syncline are presented. Field observations of flow cleavage, fracture cleavage, lineations, and joints are discussed. Lineations parallel fold axes and mostly plunge northeast, with some plunging southeast and a few southwest at a moderate to steep angle.

Introduction

The Peach Bottom syncline is located in the Appalachian Piedmont of southeastern Pennsylvania and Maryland. It extends northeastward for a distance of about 16 1/2 mi from a point near Pylesville, Harford County, Maryland, through York County, Pennsylvania, and across the Susquehanna River into Lancaster County, Pennsylvania. This paper on the deformation in the Peach Bottom syncline is part of a larger study of the structure and petrology of the Peach Bottom slate and the surrounding formations.

Formations of the Peach Bottom syncline

The Peach Bottom syncline is a tightly compressed trough which, for two-thirds of its length (the northeastern two-thirds) is overturned towards the northwest. The syncline lies in the Peters Creek schist, a series of interbedded chlorite-sericite schists and quartz-albite schists which overlie the Wissahickon schist. The Wissahickon schist may represent metamorphosed Beekmantown and Chazy sediments [SWARTZ, 1948]. The Peters Creek schist is apparently conformably overlain by the Cardiff conglomerate, which is in turn followed by the Peach Bottom slate. The slate is thought probably to be of Cincinnatian (Upper Ordovician) Age [STOSE and JONAS, 1939]. The slate is more resistant than the surrounding schist and consequently forms a ridge along the middle of the syncline. The width of the slate belt is about five-eighths mile at the southwest, but it thins considerably towards the northeast. This does not represent stratigraphic thickness. The major fault in the area parallels the strike of the syncline and cuts out the Cardiff conglomerate on the north side of the slate belt for a distance of nine miles.

Field structures

Bedding--Bedding has been superseded by schistosity as the chief S-plane. It is almost entirely obliterated in the slate, but it can be discerned at several localities where sandy intercalations are present.

Flow cleavage--A strong flow cleavage (schistosity, S_2) has been imposed on the rocks of the area. The general strike of flow cleavage is N 52°E, which is parallel to the long axis of the syncline. The dip is usually steep to the southeast, as the syncline is overturned towards the northwest, but locally S_2 is vertical and even dips steeply NW in places.

Folds--Folds in the Peters Creek schist are gentle and open at some distance from the center of the syncline. However, within a half mile of the center of the syncline, the folds become isoclinal and overturned to the northwest. Folding has affected flow cleavage planes as well as bedding. Crenulations and folds of small amplitude are common in the Peach Bottom slate. They are believed to form as a result of local inhomogeneities and drag along slaty cleavage planes. At one locality along the railroad cut on the east bank of the Susquehanna River, the south limb of a steeply plunging fold in slate is also the north limb of an adjacent horizontal fold (see Fig. 1). This illustrates rotation of the b-axis about the c-axis, so that the b-axis of one fold almost coincides in direction with the a-axis of the adjacent fold. Rotation about the c-axis accompanied rotation about the b-axis.

Fracture cleavage--Fracture cleavage is approximately parallel to the axial planes of folds and crenulations. It transects flow cleavage in all formations, but it is best shown in the slate. Flow cleavage planes are displaced along fracture cleavage planes due to differential slip or shear (see Fig. 2). Larger displacements result in slip faults. In several narrow zones fracture cleavage planes are so closely spaced, and shearing along them has been so intense, that flow cleavage is almost

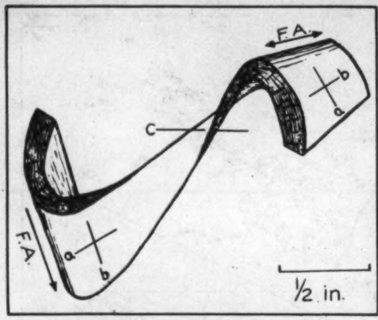

Fig. 1--Illustration of rotation of folds

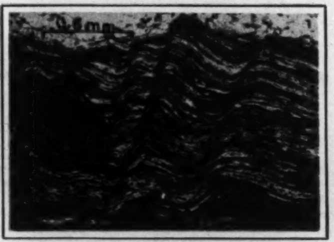

Fig. 2--Photomicrograph of fracture cleavage in Peach Bottom slate; fracture cleavage does not appear to enter quartzitic layer (top); wavy slaty cleavage planes extend from left to right

obliterated. Micaceous minerals are dragged from the flow cleavage planes into the fracture cleavage.

In several localities two sets of fracture cleavage are present; one is horizontal or gently dipping, and the other is steeply dipping.

Figure 3 is a stereographic projection of slaty cleavage (S_2) and two fracture cleavages (S_3 and S_4) in a specimen of Peach Bottom slate, where slaty cleavage locally dips northwest. One fracture cleavage (S_3) dips gently to the northwest and the other (S_4) dips steeply to the east-northeast. If the diagram is rotated so that S_2 becomes the projection plane (see Fig. 4), their symmetrical orientation with respect to slaty cleavage (S_2) becomes apparent. Other specimens possessing two fracture cleavages showed a similar relationship. The gently dipping fracture cleavage intersects S_2 in B. The two fracture cleavages, however, do not intersect in a fabric axis. The fracture cleavages are not equally developed planes of slip. According to SCHMIDT [1932], the better of the two glide surfaces lies more nearly parallel to a line of maximum shearing stress.

Fold axes--Fold axes can be measured directly in folds or they can be determined by measuring the intersection of the several S-planes (flow cleavage, bedding, and fracture cleavage). The intersection of these planes is commonly marked by a lineation. Figure 5 is a regional map of fold axes and lineations, and it also presents a schematic longitudinal section of the slate in the Peach Bottom syncline. Only a small percentage of the fold axes and lineations are horizontal. Most plunge moderately to steeply northeast, east or southeast, but a few plunge to the southwest. A stereographic projection of fold axes and lineations shows that they are distributed along the trace of the flow cleavage (ab) plane, which indicates that they have been rotated in that plane about the c-axis. The amount of rotation is different in various parts of the area. It ranges from 0° to 90° or more. Most commonly it is more than 30°.

The longitudinal section of the slate (Fig. 5) is constructed from many more readings than can be shown on the map. The lines do not indicate bedding, but rather, directions of plunge of fold axes and lineations in different parts of the syncline. In several transverse zones, the rotation of fold axes about

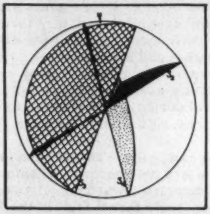

Fig. 3--Stereographic projection of slaty cleavage (S_2) and two fracture cleavages (S_3 and S_4) in a specimen of Peach Bottom slate

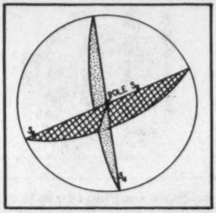

Fig. 4--Diagram of Fig. 3 rotated so that the projection plane is the plane of S_2. Pole of S_2 is at center of projection

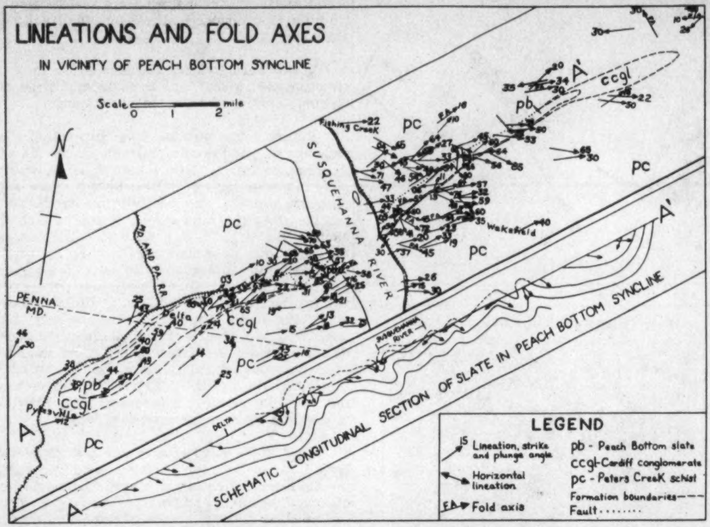
LINEATIONS AND FOLD AXES
IN VICINITY OF PEACH BOTTOM SYNCLINE
Scale 0 1 2 mile
N
SUSQUEHANNA RIVER
Fishing Creek
MD. AND PA. RR.
PENNA
MD.
Delta
Pylesville
Wakefield
pc
pb
ccgl
A
A'
SCHEMATIC LONGITUDINAL SECTION OF SLATE IN PEACH BOTTOM SYNCLINE
DELTA
SUSQUEHANNA RIVER
LEGEND
Lineation, strike and plunge angle
Horizontal lineation
Fold axis
pb - Peach Bottom slate
ccgl - Cardiff conglomerate
pc - Peters Creek schist
Formation boundaries
Fault

Fig. 5--Regional map of lineations and fold axes

c is expecially marked and cross folds are formed.

Lineations--Lineations are due to crinkling of flow cleavage surfaces or intersection of S-planes. Most frequently they are due to the intersection of flow cleavage and fracture cleavage. In several localities there are two sets of lineations, one steep and one almost horizontal (see Fig. 6). The angle of intersection is approximately 73°, but it may vary. The horizontal or gently plunging lineations are parallel to B, and the steep lineations parallel B′. Either the horizontal or the steep lineations may transect the others, thus they are largely contemporaneous. Either set may appear to be more prominent, but usually the steep lineations are not so coarse as the horizontal ones, bu however, in the specimen shown in Figure 6 the steep lineations are more coarse.

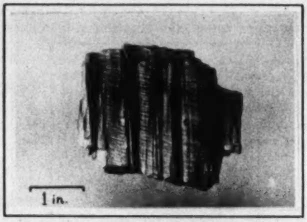

Fig. 6--Slate showing two sets of lineations intersecting in an angle of 73°; B-lineations dip gently to the right; B′-lineations are vertical; this specimen is a B∧B′-tectonite

Joints--Strike, cross, and oblique joints are present, but ac cross joints are much more numerous than the others. Cross joints are not quite normal to fold axes. Instead, they form an angle of about 80° with them. Most of the cross joints strike northwest and stand vertical or dip steeply to the northeast or southwest. Many cross joints trending slightly east of north are also present. Joints formed during a late stage in the deformation of the area, when the rocks were rigid.

Thrusts and faults--Thrusts and faults of small displacement are not uncommon. Most of the thrusts are directed toward the northwest. Figure 7 shows a low angle thrust fault in the Peters Creek schist dipping about 40° to the southeast. At the south end, the thrust fault is truncated by a steep fault which dips 75° to the northwest. Flow cleavage has a steep regional dip to the southeast and

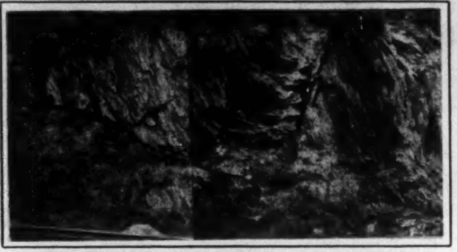

Fig. 7--Complex thrust fault in Peters Creek schist along railroad cut east bank of Susquehanna River, 1350 ft northwest of Peters Creek; view looking northeast

it is undisturbed in the schist below the thrust plane. Above the thrust plane, however, flow cleavage has been dragged into a position of parallelism with the fault. The sericitic schist was thrust northwestward. As stresses continued and sufficient relief could no longer be attained laterally, the overriding schist buckled upward, then fractured and produced the steeply dipping fault at the south end of the exposure.

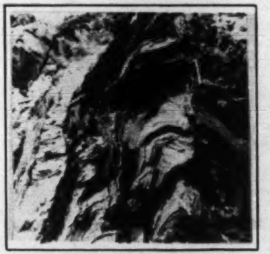

Fig. 8--Folded slate in Johnson quarry cut by reverse fault which dips steeply to north (parallel to hammer handle); white areas at left and upper right corner are quartz veins

Figure 8 shows a faulted anticline in slate in the Johnson quarry. The fault strikes about N70°E and dips about 81° to the northwest. It is marked by chloritic gouge one quarter to two inches thick. The fold axis plunges to the east (towards the observer). On the north the fold is bounded by crushed and brecciated slate and numerous quartz veins. The direction of movement is not readily apparent, but this seems to be a reverse fault, the north side having moved up with respect to the south side. This longitudinal fault is only about 350 ft southeast of and subparallel to the major fault in the area.

The major fault cuts out the Cardiff conglomerate and throws the Peach Bottom slate against the Peters Creek schist for a distance of about nine miles along the northwest side of the syncline. The fault is nowhere exposed. It is marked by a zone of deep weathering, which is about 60 ft wide along the east bank of the Susquehanna River. BEHRE [1933, p. 367] estimates the displacement along the fault at about 450 ft. The writer believes the fault plane may parallel the fault observed in Johnson quarry, in which case it may have a steep northwest dip. As the fault is not exposed anywhere, the direction of movement can only be inferred. Inasmuch as the conglomerate and part of the slate are cut out northwest of the fault, it is believed the southeast block dropped down. This may have been caused by rotation of the syncline about B when it was overturned towards the northwest. As the southeast limb and the upper parts of the syncline were thrust northwestward, the northwest limb, especially in the lower parts, was subjected to tension, thus slipping down and forming the fault.

Petrofabric evidence

Petrofabric evidence supports the conclusions drawn from field observations. Mica diagrams usually show girdles about b, but a few specimens from the Peters Creek schist show point maxima, indicating a single well developed slip plane. The girdles are most complete in the slate, indicating that that formation has undergone a greater degree of rotation than the Cardiff conglomerate or the Peters Creek schist.

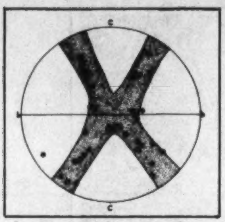

Fig. 9--Synoptic diagram of quartz maxima in Peach Bottom slate

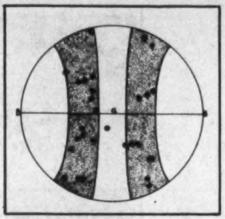

Fig. 10--Synoptic diagram of quartz maxima in Cardiff conglomerate and Peters Creek schist

The quartz fabric is later than the orientation of the micas. Partial diagrams were prepared for large strained quartz grains and for small recrystallized grains. The partial diagrams for small recrystallized grains may be expected to show deformational effects of a stage somewhat later than that represented in the diagrams prepared from large quartz grains. The maxima of diagrams for small recrystallized quartz can usually be correlated with S-planes which are younger than the S-planes to which maxima from the large quartz grains are related. The c-axes of quartz grains usually form an ac-girdle about B or B′. The girdle is not peripheral, but lies about 20° in from the periphery.

Synoptic diagrams of all quartz maxima in the slate and in the other formations were prepared. The synoptic diagram of quartz maxima in the slate shows two crossed girdles inclined to c and B (see Fig. 9). The girdles are strong and suggest that the fabric is due to a cross strain in which a is approximately equal to B′.

The synoptic diagram for specimens from the other formations shows a cleft girdle about B (see Fig. 10). The maxima are somewhat more concentrated about the IV and VI positions, which suggests the presence of (h01) slip surfaces along rhombohedral glide planes. However, the distribution of maxima all along the girdles indicates that rotation about B was as, or more, important than slip along crystallographic glide planes.

Conclusions

The Peach Bottom syncline was folded and overturned towards the northwest during one period of deformation. Deformation was not uniform throughout the syncline. Mica and quartz grains were subjected to various degrees of rotation about the fold axis, B, and also slippage along various S-planes. In places, quartz also shows rotation about B′. The rocks are B-tectonites and $B \wedge B'$-tectonites, $B \wedge B'$ is commonly about 72°, rotation having occurred about c.

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NOTES ON THE GEOLOGY OF ROCK CREEK PARK, DISTRICT OF COLUMBIA

Robert E. Fellows

(Posthumous publication. Dr. Fellows died September 19, 1949.)

Abstract--Pre-Cretaceous crystalline rocks of the Piedmont Plateau are well exposed in the valley of Rock Creek within the District of Columbia. A geologic map is presented showing the distribution of four major rock types: schist, medium-grained granite, coarse-grained biotite granite, and diorite. These are described and compared with the three types - granite gneiss, biotite granite, and diorite and metadiorite - mapped in the same area by Keith and Darton in 1901. Evidence is advanced to support a revision in the definition of the relative ages of the biotite granite and the diorite in which the author believes the diorite to be the younger rock. Several hundred Brunton readings show (1) foliation striking consistently to the northeast and dipping steeply to the northwest, (2) lineation plunging regularly and gently to the southwest, and (3) joints falling clearly into three major sets - one striking normal to the foliation and dipping vertically, the other two forming cross joints striking northeasterly and northwesterly and dipping steeply eastward. The suggestion is made that aplite and quartz dikes are related genetically to the diorite with which they commonly are associated. The linear distribution of quartz blocks lying in the surficial gravels is believed to reflect the positions of buried veins that stand as walls above the erosion surface of the Pre-Cambrian basement. Suggested projects are described to extend the scope of the present report.

Introduction

Pre-Cretaceous crystalline rocks of the Piedmont Plateau, with which this paper is concerned, are well exposed in the valley of Rock Creek within the District of Columbia (see Fig. 1). The problems of determining origin and deformational history of rocks on the Piedmont Plateau are among the most complex in the world, and because of the small size of the area mapped, final conclusions bearing on interpretations of regional geology cannot be drawn safely from the results of the present study. The main value of the present report lies in the statistical field measurements that provide a solid basis for further field and laboratory studies.

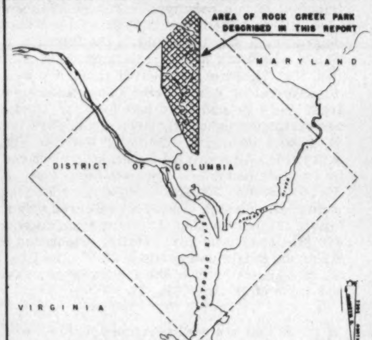

Fig. 1--Index map showing outline of area covered in U. S. G. S. Folio 70

In an effort to make this preliminary survey of maximum value to future investigators, the subject matter has been split to allow the presentation of facts apart from interpretations. To avoid confusion, rock names and age assignments of KEITH and DARTON [1901] have been retained and are presented along with suggested variations resulting from the present field work. The section on interpretation describes evidence for revising the statements of the earlier workers pertaining to relative ages of biotite granite and diorite.

The field work for the present report was carried out on weekends, holidays, and summer evenings over a period of a year and a half during 1947-1949 when the author was assigned administrative responsibilities with the Alaskan Section of the U. S. Geological Survey in the Washington office. The scope of the field project was restricted owing to the activation of an Alaskan field program that required the author's change of headquarters to Alaska.

The studies of KEITH and DARTON [1901], were carried out nearly 50 years ago when the

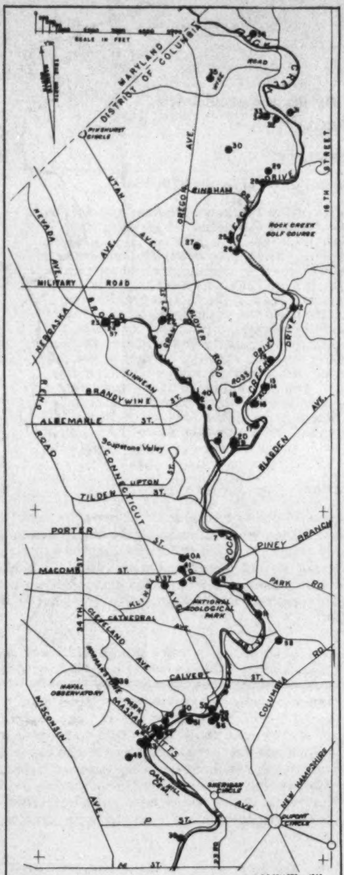
SCALE IN FEET
MARYLAND
DISTRICT OF COLUMBIA
ROCK CREEK
ROAD
PINEHURST CIRCLE
UTAH
AVE.
OREGON AVE.
BINGHAM DR.
BEACH DRIVE
16 TH STREET
ROCK CREEK GOLF COURSE
NEVADA AVE.
MILITARY ROAD
BROAD BRANCH ROAD
27 ST.
GLOVER ROAD
ROSS DRIVE
NEBRASKA AVE.
LINNEAN AVE.
BRANDYWINE ST.
ALBEMARLE ST.
RENO ROAD
Soapstone Valley
CONNECTICUT AVE.
UPTON ST.
TILDEN ST.
BLAGDEN AVE.
PORTER ST.
PINEY BRANCH
MACOMB ST.
KLINGLE ST.
PARK RD.
NATIONAL ZOOLOGICAL PARK
34TH ST.
CLEVELAND AVE.
CATHEDRAL AVE.
CALVERT ST.
COLUMBIA RD.
NAVAL OBSERVATORY
MASSACHUSETTS AVE.
WISCONSIN AVE.
OAK HILL CEM.
SHERIDAN CIRCLE
NEW HAMPSHIRE AVE.
DUPONT CIRCLE
P ST.
M ST.
R.E. FELLOWS 1949

Fig. 2--Map of Rock Creek Park showing roads and specimen localties

population of Washington was considerably smaller than it is at present. As a consequence, these early workers mapped outcrops that now are buried in the heart of residential districts. On the other hand, recent construction projects have brought to light numerous outcrops that were not exposed to Keith and Darton. Hence, much of the contradictory evidence bearing on age relations is new and different from that recorded 50 years ago. This fact emphasizes the need for checking the new evidence through additional related field mapping.

During the course of the field work 56 specimens were collected. After sorting and matching of rock types with the aid of a binocular microscope, 36 thin sections were prepared and studied in search of evidence to establish genetic relationships for the major rock types.

No data on the Cretaceous and younger formations were collected inasmuch as a map of sedimentary formations was prepared by DARTON [1947].

Description of the rocks

General statement--Four of the seven Pre-Cretaceous rock types described by Keith and Darton are exposed in the valley of Rock Creek within the District of Columbia. They are granite-gneiss, biotite granite, soapstone, and diorite and metadiorite. The distribution of samples collected for detailed laboratory study is shown in Figure 2.

Granite gneiss--The granite gneiss unit could be called, more appropriately, a schist complex. The pattern used to indicate the distribution of this rock type in Figure 3b is somewhat different from that in Figure 3a and shows diagrammatically the strike of the foliation which, with a few minor variations, is consistent (see Fig. 4). Strongly foliated rocks are well displayed along Beach Drive a few yards north from Piney Branch Road (see Fig. 5). The average strike throughout the area of the Park is 21° E. and the average dip is 72° NW (see Fig. 4, also 14). A prominent lineation is produced by elongate inclusions of quartz blebs (see Fig. 6), biotite clusters, and foreign rock fragments, all of which display a preferred orientation; (2) intersection of foliation and cleavage; and (3), less commonly, parallel orientation of stretched quartz and pyrite grains. The lineation plunges consistently to the southwest at an average angle of 31° (see Fig. 7).

Figure 8 shows the distribution and attitude of joints that are well developed within the schist complex, and a summary circular diagram (see inset, Fig. 8; also Fig. 14) representing an equal area net on which are plotted the concentrations of poles of the joint planes. The maxima define three major joint sets. A ten-per cent maximum represents a set that strikes N 72° W and dips vertically, and two eight-per cent maxima represent two sets of cross joints. One set strikes N 42° E and dips 68° SE; the other strikes N 40° W and dips 68° NE.

This schist complex comprises a diverse assemblage of rocks which collectively can be

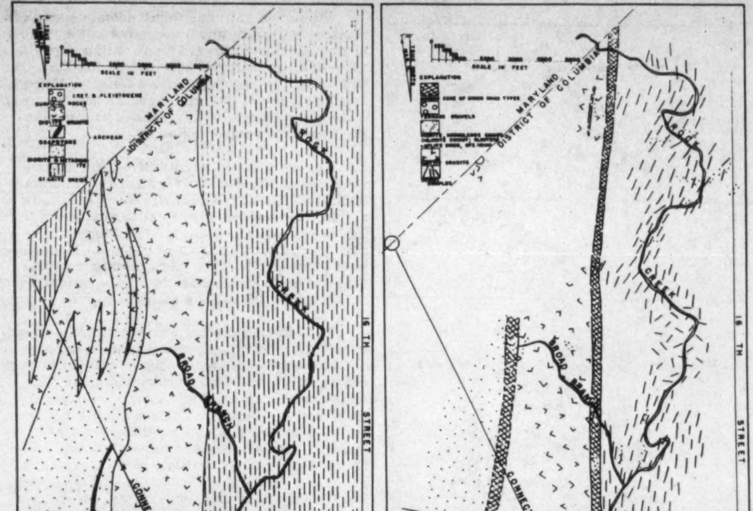
SCALE IN FEET
EXPLANATION
MARYLAND
DISTRICT OF COLUMBIA
ROCK
CREEK
BROAD BRANCH
CONNECTICUT AVE.
16 TH STREET
MASS. AVE.
NAVAL OBSERVATORY
WISCONSIN AVE.
P ST
M ST
DUPONT CIRCLE
(a)
(b)
R.E. FELLOWS 1949

Fig. 3--Geologic map adapted from U.S.G.S. Folio 70 compared with that resulting from recent mapping; (a) KEITH and DARTON [1901] (somewhat simplified); (b) as interpreted by the author in 1949

considered as quartz mica schist with more or less admixed granitic material. Laboratory studies have revealed epidote-bearing or garnet-bearing mica-feldspar-quartz schist, muscovite-quartz schists, chloritized biotite schists, and quartz-feldspar-hornblende schists that carry appreciable amounts of accessory epidote and titanite. Accessory garnet, zircon, magnetite, and apatite, and rare grains of wollastonite, enstatite, diopside, and hedenbergite were identified. Alteration products in the form of chlorite and sericite are common throughout the schist complex, and secondary calcite is a prominent constituent in fault zones.

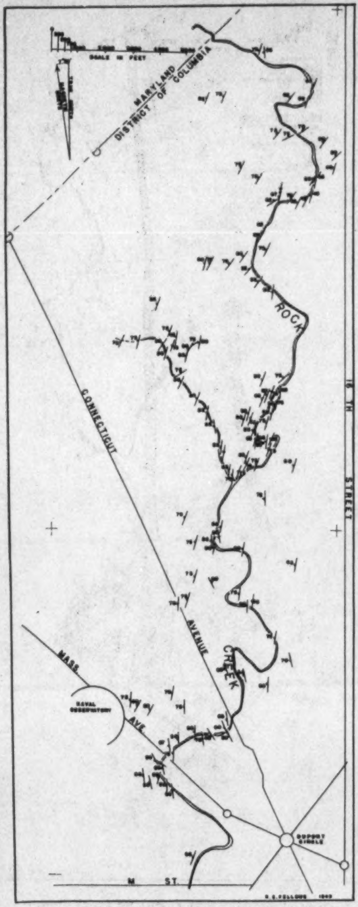

Fig. 4--Map of Rock Creek Park showing attitude of foliation

Within the unit mapped as schist complex is a massive granite which crops out in the valley of Rock Creek southward from Military Road for a distance of about 2500 ft (see Fig. 3b). This rock type was not differentiated by Keith from what he called granite gneiss (see Fig. 3a). This granite is not to be confused with the biotite granite described below.

The outcrops of the massive granite take the form of rounded boulders some of which are dislodged and moved downstream while others are in place and rounded by spherical weathering and exfoliation (see Fig. 9). Jointing is poorly developed and parallels the well-developed joint planes in the surrounding schist complex. Dikes of aplite and quartz veins are noticeably absent within the area of massive granite.

Hand specimens are characteristically moderately dark gray, salt-and-pepper rocks with common unoriented inclusions of biotite clusters, quartz augen, and less abundant fragments of light-colored, fine-grained quartz-mica schist. Thin-section study of a specimen collected from location 12 (see Fig. 2) reveals a medium-grained massive rock composed of quartz and biotite with smaller amounts of muscovite and oligoclase ($Ab_{83}An_{17}$). No potash feldspar was identified in this thin section. Accessory minerals include magnetite, zircon, garnet, and apatite.

Biotite granite--The best exposure of fresh biotite granite within the Park is in a large a abandoned quarry adjacent to Broad Branch Road about 1000 ft north from the foot of Brandywine Street (see Fig. 2, location of specimen 3). The rock exposed in the quarry is strongly jointed (see Fig. 10), moderately well foliated, and contains a few biotite clusters that form plates parallel with the foliation of the granite. The attitudes of foliation and joints within the biotite granite are parallel to those measured in the schist complex (see Fig. 4 and 8).

The biotite granite in hand specimens is a light-colored coarse-grained gneiss with prominent large biotite flakes in striking color contrast to the feldspar and quartz that together comprise 80-90 per cent of the rock. Many road cuts expose weathered biotite granite. The weathered material can be identified by the well preserved texture, the preponderance of biotite over muscovite, and the light-gray color.

Thin-section studies reveal biotite, quartz, microcline, and oligoclase ($Ab_{79}An_{21}$) with minor amounts of muscovite, garnet, titanite, and epidote. Additional petrographic work may demonstrate that the epidote, which is a common accessory mineral, has been introduced during the intrusion of the hornblende diorite and is not a primary mineral in the granite.

Hornblende diorite--Although dioritic rocks are recognizable in widely scattered outcrops through Rock Creek Park, the only area of massive diorite is at the southern end of the Park a few

Fig. 5--Foliated schist complex of Beach Drive north of Piney Branch Road; view looking north

Fig. 6--Stretched quartz augen in schist near intersection of Porter Street, Klingle Road, and Beach Drive

hundred feet south of the Massachusetts Avenue Bridge (see Fig. 3b). The rock at this locality crops out in the valley of an eastward flowing stream at the northern edge of Oak Hill Cemetery. (see Fig. 11). Outcrops are rounded because of the massive character of the diorite. Jointing is well developed and parallel to those sets identified in the schist complex and in the biotite granite, and calcite and zeolites commonly are developed on the joint surfaces. Numerous aplite dikes and quartz veins, which cut the diorite, show small offsets and drags along minor faults (see Fig. 12).

Diorite hand specimens are predominantly dark with a moderate amount of quartz forming a dull white background for the evenly distributed medium- to coarse-grained hornblende crystals. Textural and compositional variations within the mass give portions of the rock a gneissoid texture. Near the northern edge of the main diorite body platy inclusions of chlorite schist are common and lie parallel to indistinct foliation.

Keith recognized the varieties of dioritic rocks and assigned them to a group that he called diorite and metadiorite. Recognizable types, in addition to the massive hornblende diorite, are

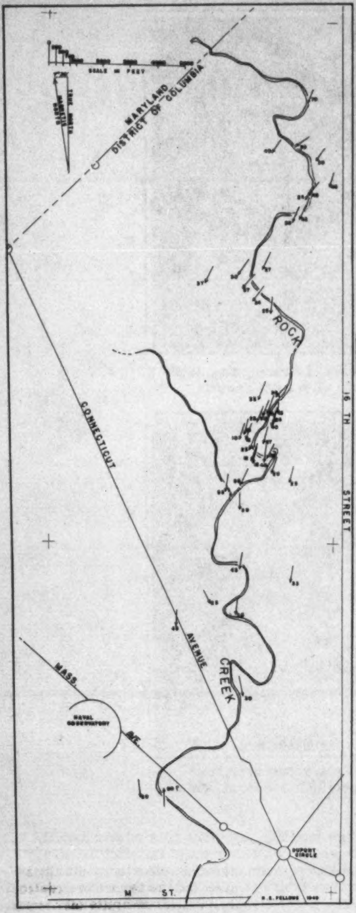
SCALE IN FEET
TRUE NORTH
MAGNETIC NORTH
MARYLAND
DISTRICT OF COLUMBIA
ROCK
CREEK
CONNECTICUT
AVENUE
MASS.
AVE.
NAVAL OBSERVATORY
16 TH STREET
M ST.
DUPONT CIRCLE
R. E. FELLOWS 1949

Fig. 7--Map of Rock Creek Park showing attitude of lineation

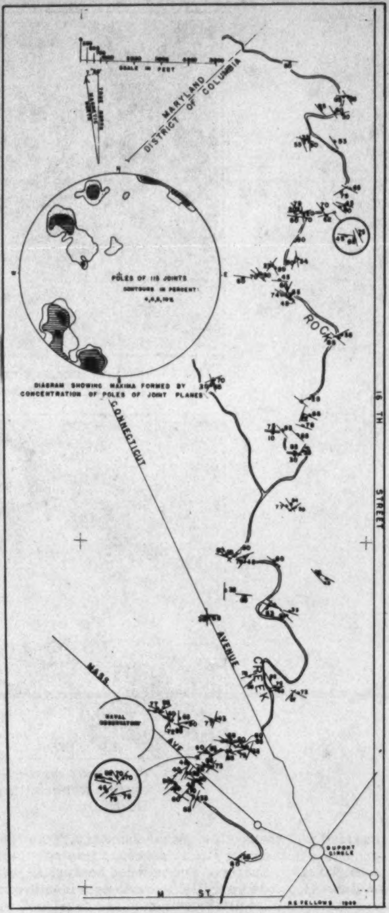
SCALE IN FEET
TRUE NORTH
MAGNETIC NORTH
MARYLAND
DISTRICT OF COLUMBIA
N
E
W
POLES OF 115 JOINTS
CONTOURS IN PERCENT
DIAGRAM SHOWING MAXIMA FORMED BY CONCENTRATION OF POLES OF JOINT PLANES
ROCK
CREEK
CONNECTICUT
AVENUE
MASS.
AVE
NAVAL OBSERVATORY
16 TH STREET
M ST.
DUPONT CIRCLE
R E FELLOWS 1949

Fig. 8--Map of Rock Creek Park showing attitude of joints

hornblende granodiorite, nearly monomineralllic hornblendite, hornblende-chlorite schist, and quartz-hornblend schist which crops out at localities 1, 6, 8, 10, and 53 (see Fig. 2).

Weathered diorite outcrops are common and are easily identifiable by their deep-red color. Studies of heavy mineral separations of carefully selected weathered material show that the red material is iron oxide developed from hornblende. Thin-section studies of two specimens from the main diorite mass show hornblende, biotite, and quartz, with accessory epidote and magnetite.

Fig. 9--Massive granite in Rock Creek south of Military Road

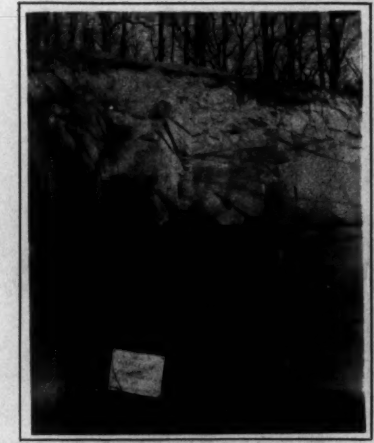

Fig. 10--Well jointed biotite granite in Broad Branch Road quarry north of Brandywine Street; view looking south

Fig. 11--Massive hornblende diorite outcrop across Rock Creek 200 yd south of Massachusetts Avenue Bridge; view looking west

Feldspar is absent, and chlorite and calcite are common secondary minerals. Much of the quartz appears to have crystallized late along foliation planes. Some quartz is strained and is partly recrystallized but most is fresh and developed as chains of grains that tend to form a microscopic lineation. Chlorite appears to have developed from biotite rather than from hornblende.

Soapstone crops out in the stream bed of Soapstone Valley (see Fig. 2) and was recognized by Keith also in the area of the National Zoological Park (see Fig. 3a). No effort was made to outline the areas of soapstone on the revised geologic map (see Fig. 3b) inasmuch as it is not considered a mappable rock unit.

Fig. 12--Sheared aplite dike in quarry on west side of Rock Creek 100 yd south of Massachusetts Avenue Bridge

Fig. 13--Aplite dikes cutting red weathered diorite near Oregon Avenue extension; view looking north

The large majority of outcrops of hornblende diorite contain dikes and stringers of both quartz and aplite (see Fig. 12 and 13). Many dikes of both rock types are concordant with the host rock, but cross-cutting relationships are common especially in the zone of mixed rocks. On Normanstone Drive (see Fig. 2, locality 38) a vertical aplite dike, six inches thick, is concordant with the biotite granite host and is foliated parallel to its own borders. The largest measured thickness of the aplite dikes is 40 ft (Fig. 2, locality 51); whereas the majority of the aplite dikes, and the quartz veins, range in thickness from fractions of an inch to three feet.

Hand specimens of the aplite closely resemble muscovite-quartz schist or highly metamorphosed quartzite. The aplite dike rocks contain 75-90 per cent of quartz and feldspar. The remainder is muscovite with minor amounts of accessory epidote, garnet, zircon, apatite, and biotite. The quartz: feldspar ratio ranges from 40:60 to 65:35. The quartz characteristically is at least partly recrystallized and shows a preferred crystallographic orientation.

One pegmatite dike was discovered (Fig. 2, locality 55) cutting across boundaries of hornblende

schist and diorite in the zone of mixed rocks. The dike is about ten inches thick, pink in color, and contains a large proportion of pink feldspar and muscovite with a moderate amount of quartz. Muscovite plates are as much as two inches in diameter.

Gold-bearing quartz--Gold has been reported from Rock Creek Park as a minor constituent in certain quartz veins. The author made no effort to find the gold-bearing quartz bodies or to determine any structural or mineralogic control for the deposition of gold. Mineralogic examinations and chemical analyses on carefully selected samples, along with information presented herewith, should bring to light the geologic factors that have influenced the gold mineralization. Several gold-bearing quartz veins have been mined in nearby areas and additional field evidence undoubtedly would be available from examinations of underground workings and samples of the ore.

Galena has been reported, and pyrite is a common accessory constituent in the quartz veins and in several facies of the schist complex.

Summary of structural geology

Figure 14 shows the relationships between the major megascopic structures. Attitudes of foliation, lineation, and joints are remarkably consistent throughout the mapped area, and are not appreciably affected by lithologic variations. The planes, plotted on an equal area net, represent average attitudes as defined by maxima that are derived by plotting and contouring points of penetration, in the lower hemisphere, of poles of the planar structures (see inset, Fig. 8). The strike of the major set of joints is roughly normal to the strike of the foliation. The set, however, does not represent true "ac" jointing, inasmuch as lineation is not perpendicular to the statistical joint plane. The strikes of the joints represented by eight per cent maxima are essentially mutually perpendicular and the planes can be considered as normal cross joints. Lineation is measurable on the foliation plane and plunges gently to the southwest.

Interpretation of facts

Age relations--Although evidence bearing on age relations of the rock types is scanty within the Park it seems certain that the schist complex (Keith's granite gneiss) is the oldest exposed rock unit. Evidence based on interpretations of present outcrops suggests that the diorite is younger than the biotite granite. The geologic time table on Figure 3b shows the relative positions of these rock units reversed from that shown on Figure 3a.

Interpretation of evidence of intrusive activity--An outcrop on Adams Mill Road near the intersection of Harvard Street shows diorite clearly cutting through deeply weathered biotite granite. Diorite fingers extend into the granite and with increasing distance from the main dike tend to branch out, become thinner, and grade into iron-stained quartz. Numerous aplite dikes cut the granite and the diorite at this outcrop and lend support to the supposition that the aplite and quartz are differentiates from the diorite magma. At the western end of this exposure is an outcrop of schist that is in contact with the biotite granite.

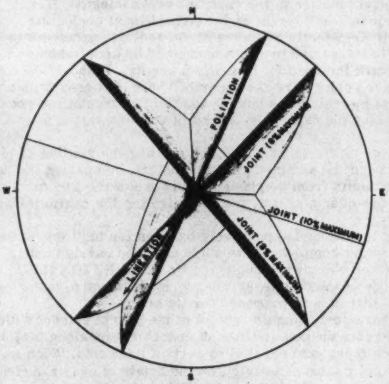

Fig. 14--Equal area plot showing relation of major structural elements

It is suggested that the zone of mixed rocks (see Fig. 3b) was developed during, and as a consequence of, the intrusion of the diorite accompanied by injection of aplite, and development of quartz veins. Outcrops within the zone show marked effects of intrusive activity in the form of aplite dikes, amphibolite dikes, heavy concentrations of quartz, xenoliths, bodies of soapstone, extreme contortion, and slickensiding. The suggestion is supported further by the fact that the zone of mixed rocks is widest in the area adjacent to the massive hornblende diorite. The diorite magma is believed to have followed a zone of weakness at the border between the schist and the biotite granite and to have been

intruded at the expense of easily replaceable facies of the schist.

Origin of rock types--More detailed mineralogic studies may demonstrate whether the quartz-hornblende schists, which are interbedded with other facies of the schist complex, represent metamorphosed limy sedimentary rocks, whether they have developed through an admixture of igneous material, or replacement by it, or whether they represent thin lenses of injected material from the diorite magma. It should be noted that each of these samples lies within or close to the zone of mixed rocks.

The entire schist unit appears to have been granitized. The rocks lying farthest north along the strike of the schist show the least effect, whereas the granitic component increases toward the area of massive rock immediately south of Military Road (see Fig. 3b). Several outcrops of schist in the vicinity of the massive granite show extreme contortion and drag folds. The fact that aplite dikes and quartz veins are absent within the massive granite is probably a consequence of the massive character of the granite, which made it inhospitable to the penetrating solutions.

Origin of quartz blocks--The regular linear distribution of quartz blocks that commonly lie in the gravels on the wooded hills suggests that they directly overlie buried veins. Although more than one cycle of the formation of quartz veins may be involved, probably most of the quartz distributed through the Park was introduced during the late stages of the intrusion of the diorite. The solutions which formed the quartz veins followed zones of weakness in the country rock where the foliation or schistosity was nearly vertical. Previous to the deposition of the Cretaceous sediments the basement rocks were denuded, and owing to greater resistance to erosion, the quartz veins formed walls protruding from the surrounding country rock. Gentle subsidence of the land, beginning in the Cretaceous period, resulted in the deposition of a mantle of gravel that partly or entirely buried the quartz walls. As a result of recent uplift of the land and partial erosion of the gravel mantle, portions of the quartz veins have been exposed. Many have collapsed as a result of the continued effects of erosion and lack of support, and now appear as loose blocks without apparent bed rock connections.

Slight recent movement may have had considerable effect in causing the collapse of the quartz walls. The evidence of the recent movement is seen best in outcrops of weathered biotite granite and diorite and takes the form of small-scale jointing that gives the rock a checked appearance. Small crystals of tourmaline commonly fill joint cracks that appear as extremely thin black lines against the gray or red color of the weathered rock.

Recommendations for additional studies

The variety and complexity of geologic subject matter in the environs of Washington, D. C. should provide a strong impetus for the development of interest on the part of local geologists. Several projects are outlined below relating either directly or indirectly to geologic problems in Rock Creek Park. They represent only a few of the varied projects that could be undertaken as logical extensions of the field and laboratory work included in the present report. It should be noted that problems related to Cretaceous and younger geology are not described here, but constitute a large field of endeavor for those whose interest or training is outside the field of crystalline rocks. Some of the more interesting problems concerning the crystalline rocks of the Washington area are as follows:

(1) A study of the petrography and petrology of the schist complex including the plotting of metamorphic mineral zoning, identifying and describing the admixed granitic content, comparing the complex with the Wissahickon schist and other rock units from neighboring portions of the Piedmont Plateau, determining the origin of the hornblende-quartz schist, and investigating the character and origin of the inclusions.

(2) A study of the petrography of granites to distinguish positively between the biotite granite and that which appears to have granitized the schist complex. This study could be carried out in conjunction with a study of rock analyses, a few of which were published by WASHINGTON [1921].

(3) A study of the petrography and petrology of the diorite-aplite-quartz sequence to substantiate further or refute the differentiation hypothesis that is here proposed for its origin.

(4) A detailed study of the distribution, character, and gold content of the quartz veins. Within Rock Creek Park the distribution of quartz suggests the possibilities of concentration along major shear zones, along contacts between major rock types, and parallel to certain joint sets. Such a study also might shed light on the age, or ages, of intrusive activity, on the origin of quartz-augen in the schist complex, and on lithologic or structural control of the deposition of gold.

(5) An analysis of joints to determine their relationship, or lack of it, to the origin of planes of liquid inclusions that have been studied by TUTTLE [1945 and 1949] in the vicinity of Washington. Preliminary analysis of the joint pattern, as described in the present paper, suggests a possible

genetic relationship between the prominent set of joints striking N 40° W and dipping 68° NE and the planes of liquid inclusions that, within the area of the Park, closely parallel this joint set. Such a study also would relate the major jointing to the tourmaline-filled joints that here are described as evidence of recent movement.

(6) A study, with the use of an auto-radio, of the distribution of structural breaks in rocks underlying the street and highway system of the District of Columbia. This approach has been described by CLOOS [1934] and would be particularly well adapted to thickly populated residential areas where outcrops are scarce.

(7) An analysis of lithology and structure within Rock Creek Park to determine the physiographic history of Rock Creek valley.

(8) A structural analysis of the outcrop on Adams Mill Road near the intersection with Harvard Street. All major rock types in Rock Creek Park are represented in this outcrop and a careful study of the amount and direction of movement may offer clues to aid in positively determining the relative ages of the rock types, and the ages and intensity of the movement.

Acknowledgments--The author had the able assistance and genial companionship of his wife, Mary S. Fellows, throughout the course of the field mapping. Special acknowledgment is due John C. Reed, Jr., and Richard G. Ray for numerous helpful discussions both in the field and in the office.

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CURRENT NAVAL RESEARCH IN LAND AND SEA ICE

Charles C. Bates and Gordon G. Lill

Three oceans bound the shores of North America. The U. S. Navy maintains major fleets in two of these. The third ocean is shunned because its surface happens to be predominantly solid. The methods developed through past centuries for the utilization of a sea fail almost completely in the Arctic. This failure of knowledge and techniques provides an unusual challenge to the geophysicist. Some of the naval research now underway on land and sea ice may eventually lead to making this type of ocean of some use to society.

In past years, the non-existence of an extensive and continuing research program into the growth, movement, and disintegration of ice in polar regions can probably be ascribed to the lack of suitable transportation and suitable motives. The shortage of transportation is being rapidly eliminated by such technological advances as the long-range aircraft, the modern ice-breaker, JATO-equipped and rotary-winged aircraft, and the impending development of a true submarine. The difficulties involved in supplying the northern weather station network and the Naval Petroleum Reserve Number Four at Point Barrow, Alaska, have resulted in a renewal of scientific interest in the problems of sea ice. This, together with a new-found interest in the natural sciences of the Arctic, has resulted in a worthwhile motive for trekking to the northern latitudes.

With the stumbling blocks removed, the geophysicist is now free to develop a research program which will determine the best ways to utilize the Arctic Ocean. The basic premise of such a program is that an efficient operation is one which uses, rather than fights, the natural environment. At first inspection it would appear that the ice floes of the Arctic Ocean might be likened to a series of floating, unstable islands. This concept has already been utilized by the Russians for some years. A particularly notable example is one in which an ice floe served as the means of transport for a scientific station which drifted from the North Pole to the east of Greenland during 1937. This method was improved when, rather than waiting for an ice floe to drift to new locations, the Russians landed aircraft on various ice floes in order to conduct scientific work. A case in point was Cherevichny's flight to the so-called Pole of Inaccessibility in 1941. Even this method was improved upon when the British conceived and partially executed Project Habbakuk. Their project would have provided a two-million ton aircraft carrier constructed of Pykrete, a synthetic building material composed of frozen water and wood-pulp [PERUTZ, 1948]. In the case of Habbakuk, an ice-floe would have been built to order and with self-propulsion, thus going Mother Nature one step better.

Before the design engineer can markedly improve such applications as these, a better knowledge of the Arctic Ocean is required, particularly with regard to the nature and behavior of floating ice. Learning of this kind may be obtained in four steps. The first of these is to interest and acquaint geophysicists with the problem; the second, to develop equipment and techniques capable of conducting the necessary scientific investigations and surveys in a severe environment; the third, to carry out the research and surveys; and finally, to develop the required theories and techniques for explaining that which is observed in the Arctic Ocean and for predicting the various phenomena before they occur.

Since formal training in cryology is limited to scattered courses in glaciology and regional oceanography, the Navy has had to rely on the premise that experience is the best teacher. The initial approach was to have oceanographers accompany such naval cruises as those to the Antarctic in 1946-1947, to the Canadian Archipelago in 1946, 1947, and 1948, and to Point Barrow in 1948. The troubles encountered when attempting to conduct scientific work during an operational cruise indicated a better solution would have to be found. As an example of the problem it is worth noting: in the summer of 1948 one of the oceanographers took an ice auger north for testing, and though the cruise lasted four weeks in Arctic waters no opportunity was presented for going onto the ice to test the equipment.

Because of considerations such as these, as well as numerous others, the Office of Naval Research established a research facility, the Arctic Research Laboratory, at Point Barrow, Alaska, in 1947 [SHELESNYAK, 1948]. Through the efforts of the Bureau of Yards and Docks and the Director, Naval Petroleum Reserves, adequate laboratory facilities are now present and will be further expanded as opportunity permits. At present, about thirty-five scientists are working at the laboratory; of these, four are working on sea ice and other geophysical problems. Because of a recommendation of the laboratory's Advisory Committee, it is expected that the percentage effort now devoted to physical problems will gradually increase over a period of years.

The Office of Naval Research, the Navy Electronics Laboratory, and the Navy Hydrographic Office, plus two ONR contractors, the Woods Hole Oceanographic Institution and the Scripps Institution of Oceanography, are participating in a joint oceanographic program at the Arctic Research Laboratory. The program calls for the rotation of teams of scientists at approximately two-month intervals throughout 1949-1950. The first team, composed of W. G. Metcalf and J. F. Holmes of the Woods Hole Oceanographic Institution, initiated the program in Februrary, 1949, and was relieved by B. Holtsmark and R. Rowray from the Navy Electronics Laboratory. While such short stays are recognized as too brief for detailed studies, the plan will permit twelve men per year to become acquainted with Arctic research. It is hoped that some of these individuals will eventually be able to formulate detailed research programs and return to Point Barrow to carry them out.

Although it may appear to be strange that the Navy should concern itself with the problems of land-ice, there are good and sufficient reasons for this interest. Consider, for instance, that an appreciable portion of the ice floating in the sea comes from glaciers, and that the Navy has some rather unique problems of construction because of the difficulties presented by permanently frozen ground.

The physical properties of Alaskan glaciers have been studied by SHARP [1948] through the aid of a research contract with the Office of Naval Research. His work constituted a part of a larger operation carried forward under the direction of the Arctic Institute of North America. The usual glaciological studies of structure, movement, and melt-water circulation were made in addition to some new work in radar soundings and the heat budget of an ice-field.

The results of Sharp's work are purely preliminary. However, it can be reported that the drilling of test holes in the glacier met with considerable success. A depth of 204 ft was attained by means of an electrically heated hot-point activated by current from a small gasoline engine generator. The drilling time ranged from 1.6 min/ft above 64 ft, to 8.5 min/ft at greater depths.

In addition to Sharp's studies of glaciers, Earl Droessler of the Geophysics Branch, Office of Naval Research, collaborated with Hans Ahlmann in investigations of the small valley glaciers in the Kebnekjse massif, Swedish Lapland, from July 18 to August 12, 1948. Their work was concerned chiefly with ice crystal measurements in relation to glacier movement and the location of the crystals within the glacier [AHLMANN and DROESSLER, 1949].

Because of the peculiar troubles presented to the construction engineer by the presence of permanently frozen ground, the Bureau of Yards and Docks has begun a research program on the problems of permafrost. The U. S. Geological Survey will carry on the program at Naval Petroleum Reserve Number Four. The first phases of the project began early in the spring of 1949, principally with the initiation of a series of thermal studies, and various electrical measurements involving investigations of natural potential fields and electrical resistivity measurements of the permafrost. During 1948-1949, the Naval Ordnance Laboratory has been interested in similar measurements of sea ice.

In planning the development of equipment and techniques for quantitative investigations of sea ice, it has been considered that spot studies could be patterned after the concepts and equipment used in soil mechanics, while regional studies could be patterned after those used in meteorology. In the case of spot observations, it appears that the most feasible way to move from location to location is by airlift. The first exploratory flights of this nature are yet to be made by United States scientists.

The Frost Effects Laboratory of the Corps of Engineers is currently developing an ice mechanics field test kit for the Hydrographic Office. This kit will permit the determination of ice thickness, density, salinity, temperature, crystal structure, and behavior under stress from the forces of shear, tension, and compression. The tests will be made on the entire vertical section of an ice-floe. The success of such a kit will depend upon the development of a light-weight coring instrument and it is believed that this device is now availible. The pilot model, when tried at Point Barrow in an air temperature of -35°F., provided continuous cores 2.5 inches in diameter and penetrated five feet of sea ice in ten minutes. If the remainder of this equipment proves equally successful, the kit may provide a basis of instrumentation for ice observations to be made throughout the Arctic by civil and military observers in the same manner that the snow kit of the National Research Council of Canada has provided a new basis for the observation of snow.

Before adequate regional studies of sea ice can be conducted, it will be necessary to have a standard nomenclature. Much of the existing ice terminology has been constructed around narrow geographic concepts, rather than designed for world-wide usage. With the ice-breakers of the U. S. Navy and Coast Guard shifting from one polar region to the other in the space of a few months, it is apparent that the luxury of terminologies based on geographic localities must be dispensed with. MAURSTAD [1935] made the first step toward an universal nomenclature. Because his Atlas is not readily available to ships of the Navy, and for other considerations, the Hydrographic Office is now preparing an extensively illustrated Functional Glossary of Ice Terminology. Since the International Meteorological Organization also has a sub-committee working on the problem of sea-ice nomenclature, the resulting terminologies will be coordinated before publication.

The International Meteorological Organization has also developed codes for reporting ice conditions. These codes, however, are largely based on the concept that their use will be primarily by merchant vessels and that the point of observation can be no higher than the masthead. Since full-time ice observers can often be assigned to military operations in high latitudes and have the use of helicopters and long-range reconnaissance aircraft, the Hydrographic Office has developed provisional codes and track charts for reporting ice in detail from both shipboard and aircraft (see Fig. 1).

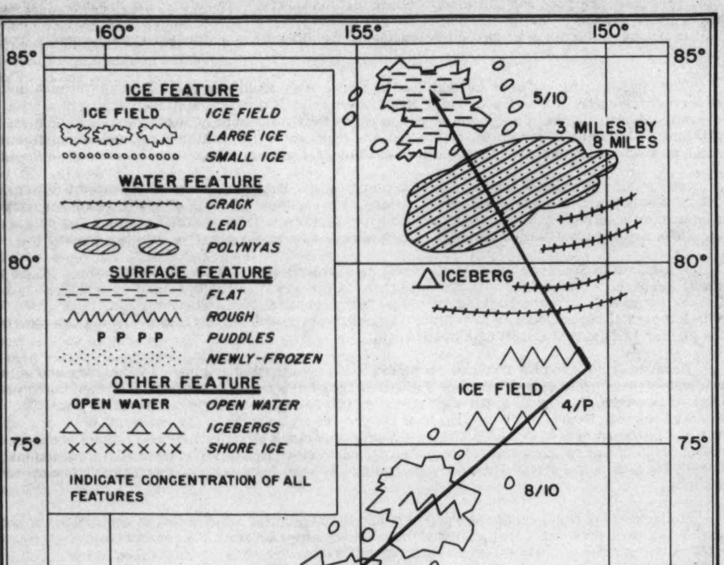
160°
155°
150°
85°
80°
75°
70°
ICE FEATURE
ICE FIELD
ICE FIELD
LARGE ICE
SMALL ICE
WATER FEATURE
CRACK
LEAD
POLYNYAS
SURFACE FEATURE
FLAT
ROUGH
P P P P
PUDDLES
NEWLY-FROZEN
OTHER FEATURE
OPEN WATER
OPEN WATER
ICEBERGS
SHORE ICE
INDICATE CONCENTRATION OF ALL FEATURES
5/10
3 MILES BY 8 MILES
ICEBERG
ICE FIELD
4/P
8/10
5/10
UNLIMITED BY 150 FEET
6/10

Figure 1--Sample of proposed chart of ice observer's tracks

These techniques have been undergoing tests for nearly a year in order to determine the extent of information it is possible to acquire on a routine basis. The testing of aerial reporting methods has rested chiefly with the 375th Reconnaissance Squadron of the U. S. Air Force, and their efforts have been most praiseworthy. Because the Squadron conducts the famed Ptarmigan flights to the North Pole from Fairbanks, Alaska, a mass of ice information is being accumulated on the area between Alaska and the North Pole. This phase of the research program is being conducted in cooperation with the Air Weather Service.

Since the behavior of floating ice cannot be understood without a detailed knowledge of the behavior of the supporting water, the Hydrographic Office has also let a contract to the Woods Hole Oceanographic Institution for the development, testing, and delivery of pilot models of instruments required for Arctic oceanography. The chief items of equipment now under development or contemplated are a light-weight winch that can be used from ice-floes, a meter for rapidly determining the salinity of melted ice samples, and an instrument which can be used to determine oceanic depths from an ice-floe. Need for the latter instrument is particularly urgent when it is realized that only eleven accurate soundings exist for the sector bounded by the North Pole, the Canadian Archipelago, Alaska, and the 180th Meridian. Existing deep-sea sounding equipment is unsatisfactory because of weight and power requirements. The instrument presently under development will utilize a small explosion for an energy source, with recording of the reflected energy by geophone or hydrophone connected to a Brush oscillograph. The Navy Electronics Laboratory has also devoted some attention to Arctic oceanographic gear and is currently developing two Arctic winches, one of which is gasoline-powered and the other, hand-powered. The Bureau of Yards and Docks is interested in obtaining an instrument which can determine ice thickness quickly and accurately for its tractor trains, and has a development contract for such an instrument with the Radio Corporation of America.

There has been little development of prediction techniques for North American ice conditions outside of the region surveyed by the International Ice Patrol. Such techniques should be feasible if the energy budget of the ocean is understood. The problem is complicated. Heat can be added or subtracted from both the top and bottom of the ice sheet, while stress can be exerted from the top, bottom, the sides, and even internally. It is unlikely that much progress will be made until considerably more is learned about the thermal structure, heat budget, and currents of the Arctic Ocean, as well as the mechanisms by which stress is transmitted and ice plates fracture. Considerable progress should be possible within our generation. Within the present decade, daily weather maps of the Northern Hemisphere have become available for the first time, as has extensive and repeated aerial reconnaissance of ice-covered waters. In addition, oceanography is entering the synoptic phase because of markedly improved instrumentation.

If the Arctic Ocean is to be changed from a useless ocean to a useful one, large scale efforts of research teams will be required to make use of the available knowledge existing in such sciences as meteorology, oceanography, soil mechanics, and geology. All this must be done with the help of modern modes of transportation. The aid, suggestions, and interest of all geophysicists are solicited in order that the study of one of the world's most abundant minerals, ice, might receive the attention it merits.

Acknowledgments--The writers desire to acknowledge gratefully that many of the concepts expressed in the paper are a result of stimulating discussions with various individuals, particularly with R. H. Fleming, L. P. Allen, and A. R. Gordon, Jr. Special acknowledgment is also made to L. P. Allen for his preparation of the ice track chart and for making available an unpublished manuscript entitled, "Polar Ice."

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DISCUSSION OF "CAN THE VELOCITY OF PROPAGATION OF RADIO WAVES BE MEASURED BY SHORAN?"

by CARL I. ASLAKSON

[Trans., v. 30, pp. 475-487, 1949]

W. H. Holmes (905 Forty-Sixth St., Sacramento 16, Calif.)--Aslakson's paper which deals with the velocity of radio waves, assumes that the velocity of light and the velocity of propagation of radio waves are theoretically identical in vacuo. This is the usual assumption, however, the sole purpose of this discussion is to promote some test or tests to confirm or deny the same.

The question of the nature of light has been a controversal subject since the days of Newton. The writer has no intention to continue the controversy. Certain physical phenomena indicate light travels through space in continuous waves but other equally reliable data indicates that light is of the nature of particles traveling in space. Such incompatible concepts or apparent contradictions have retarded scientific progress. May we instead, consider these concepts only as limitations of the imagination and use them interchangeably with an open and unbiased mind.

Measurements of the velocity of light have been made on the assumption that light is a wave motion and the velocity of propagation thereof is a constant. The only problem was to find the value of this constant.

In 1931-1933, a test to measure the velocity of light was started by A. A. Michelson and completed by F. G. Pease and F. Pearson on the Irvine Ranch near Santa Ana, California. The test was made in a vacuum tube about a mile long, but the source of light was a carbon arc, located outside the tube and subject to changes of atmospheric pressure. Variations of velocity were found which could not be accounted for. The writer searched the Pease and Pearson report for a clue as to the cause of the wide range in results.

As a general practice, a series of readings, usually about 12, were taken on one evening. As an example, on January 13, 1933, Series 198 was made from 19^h10^m to 19^h30^m and an average velocity of 299,786 km/sec was found. On January 16, 1933, Series 199, taken from 19^h57^m to 20^h30^m gave a velocity of 299,761 km/sec. This drop in velocity of 25 km/sec from the prior series must have caused some rechecking of the equipment, as a new Series 200, started at 23^h53^m and continued until 00^h24^m January 17, gave a velocity of 299,749 km/sec. This velocity was lower than the prior questioned velocity and the operators must have been even more puzzled. Breaking all precedent for night work, they started Series 201 at 03^h03^m and continued to 03^h37^m and found the velocity had returned to 299,767 km/sec.

The published records did not indicate that barometric pressure was considered or even recorded during the test. The United States Weather Bureau has a recording barometer in Los Angeles, some 33 mi from the test tube. The barometer dropped sharply during the evening of January 16 and rose again early in the morning. Thinking in terms of light being particles, here was a clue that the initial velocity of light was subject to the pressure surrounding the source.

Assuming that the barometric pressure in Los Angeles, for any specific time, was the same as that at the testing grounds for the same time, the writer compared the velocity with the barometric pressure for the corresponding time and found a direct relation between pressure and velocity. Series numbered 187 to 233 have relationship between velocity and pressure of $V = 299{,}772 + 19.8\ (P - 29.69)$ where P is in inches of mercury.

The writer does not claim that the above comparison should be considered as absolutely reliable and conclusive data, but this evidence may be sufficient to justify someone with a properly equipped laboratory and staff to repeat the test in such form as to use several atmospheres range of pressure surrounding the source of light. Also, instead of using a carbon arc, many different incandescent solids or even luminous gases and the new high-voltage Krypton light should be tried as the light source.

If light is of the nature of particles breaking away from the atom, it would be only normal to expect that the velocity of these particles would have an initial velocity proportional to the pressure surrounding the source, similar to the velocity of steam passing through a small orifice from a boiler, has an initial velocity proportional to the pressure of the boiler. Thinking in terms of the wave nature of light, Humphrey in 1895 found that an increase in pressure around a light source increased the wave length. No mention was made of approportional decrease in frequency. Here is another clue that the initial velocity of light with reference to its source is a variable depending on the condition surrounding the source. In conclusion, if the initial velocity of light has some relation to the type and conditions under which the light is operated, it could not be expected that the velocity of radio waves would have the same velocity as light.

Carl I. Aslakson (U. S. Coast and Geodetic Survey, Washington, D. C., Author's closure)--Holmes' comment on the correlation of atmospheric pressure with the variations in the results of Michelson's observations is interesting. However, limited data are presented and errors are not discussed. It is not unreasonable to expect the correlation during the period under discussion to be coincidental. Nevertheless, I am in full agreement with Holmes in believing that data such as pressure, temperature, vapor pressure, and relative light intensity should be observed during all experimental measurements. Another correspondent wrote at some length advocating an attempt to correlate the results with the relative intensity of the light source.

The writer desires to emphasize that he made no attempt in his paper at theorization regarding the nature of light, but merely presented facts which seemed to indicate that the internal consistency of the shoran measurements was better than the previous light-measurement results. It is therefore highly desirable that the rotating mirror measurements be repeated with improved equipment. Such equipment now seems to be available. J. W. Beams, Rouss Physical Laboratory, University of Virginia, has developed a rotating mirror which is reported to rotate at speeds greater than 100,000 rps, and with an angular velocity maintained with a uniformity of one part in 10,000,000. With such equipment it should be possible to determine the velocity of light within one part in 1,000,000. It has been suggested that a test be made in air over a distance of one to two miles, and that pressure, temperature, and vapor pressure be observed simultaneously; the temperature can be monitored with considerable accuracy by acoustic methods, microbarographs can be used, and psychrometric observations can be made at the ends of the base and at other points if necessary. The data thus derived should prove valuable in substantiating or improving the present empirical relationship of the index of refraction to pressure, temperature, and vapor pressure.

Table 1--Velocities of wave propagation observed by ESSEN [1948]

Frequency	Velocity in vacuum
mc/sec	km/sec
3,101.25	299,793
3,563.80	299,791
3,101.28	299,796
3,563.77	299,789
Mean	299,792.2

The reaction to my paper through private correspondence has been surprising and gratifying. In this correspondence, numerous questions were asked which indicate the desirability of clarifying certain points.

The papers of BERGSTRAND [1948] and ESSEN [1948] are now in my possession. Essen's observations were made in vacuo. His values are shown in Table 1.

Bergstrand used infrared light with a wave length of between 5000 and 6000 A. His final result was 299,796 km/sec. However, he used 1.000295 as the index of refraction of dry air at standard conditions. A more recent value of 1.0002835, which has been quite generally accepted, was used in my paper. If Bergstrand's value is modified for this difference in the index of refraction, it becomes 299,792.4. Bergstrand did not correct for the moisture content of the air but he noted that any error from this source would be of the order of one in 3,000,000.

In my paper, the shoran frequencies were not mentioned, and some readers erroneously assumed that the frequency of the timing crystal mentioned indicated the transmission frequency. The shoran air-to-ground frequencies are within the range 230-250 megacycles and the ground-to-air returns from both stations are on a frequency of about 300 megacycles.

There are now three investigators in different parts of the world, using widely different methods and frequencies, whose final results are in remarkable agreement as shown in Table 2. Although the close agreement of the decimals in the above values must be considered as coincidental, it seems highly probable that the exact agreement of the units may be significant. Certainly, in

Table 2--Summary of recent velocity investigations

Observer	Method	Wave length	Result	Remarks
		cms	km/sec	
Bergstrand	Kerr cell-photocell measurements of moderate distances (4.2 to 9.1 km)	5 to 6 × 10^{-5}	299,792.8[a]	Measurements in air and corrected for pressure and temperature
Essen	Electrical resonance of short wave guide	8.6 to 9.7	299,792.2	Measurements in vacuo
Aslakson	Shoran measurements of long distances (67 to 267 mi)	86 to 100	299,792.3	Measurements in air and corrected to vacuo for pressure, temperature, and vapor pressure

[a] A letter from Bergstrand to the author dated January 28, 1950, stated that this is his final value, based on additional measurements with improved equipment.

view of the importance of this constant, the evidence is sufficiently strong to indicate the desirability of further research.

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DISCUSSION OF "SOLIDS IN STREAM FLOW"

by GERARD H. MATTHES

[Trans., v. 30, pp. 421-426, 1949]

James F. Halsey (Research Assistant Professor of Fluid Mechanics, Dept. of Theoretical and Applied Mechanics, University of Illinois, Urbana.)--Briefly stated Matthes' contentions are: (1) Stream regimen is dependent, in part, upon the amount of solids entrained in, or transported by, the stream. (2) Regimen is upset whenever man alters any of the physical characteristics of the stream's drainage basin and/or the stream itself. (3) Unless the full significance of (1) and (2) is recognized the future generations of America will inherit streams whose discharge capacity is irreparably damaged. This discussion will cover the last two points.

The writer has just completed a study of literature [CHIEF OF ENGINEERS, 1879-1948; SALISBURY, 1937], and field data of the United States Geological Survey for the Atchafalaya River Basin, Louisiana (see Fig. 1), which lends credence to the second contention. Since the early 1800's when a portion of the main channel of the Atchafalaya River was choked with rafts of driftwood, the regimen of that stream has been constantly changing as the result of man's labors in its basin and channel.

The extension and completion of the main levee lines to Mile 57 by 1933 enabled the stream to develop a well-defined channel capable of carrying high discharges from the Red and Mississippi Rivers and Bayou des Glaises. Downstream from Mile 57, however, the river lost itself in a maze of tortuous waterways and tidal lakes whose channels possessed very poor hydraulic properties, thereby causing extensive sedimentation and a raising of the stream profile.

In order to develop the lower reaches of the Atchafalaya so that they would be capable of ful-

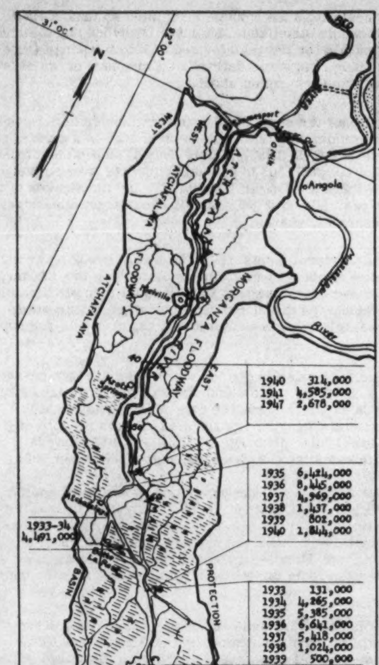
31°00'
92°00'
N
RED
WEST
ATCHAFALAYA
ATCHAFALAYA RIVER
Angola
MORGANZA FLOODWAY
FLOODWAY
Melville
Krotz Springs
River
EAST
40
PROTECTION
BASIN
PROTECTION
GRAND
LAKE
LEVEE
LEVEE
SIX MILE LAKE
WAX LAKE OUTLET
TO GULF
Morgan City
30°00'
91°00'
1940 314,000
1941 4,585,000
1947 2,678,000
1935 6,424,000
1936 8,445,000
1937 4,969,000
1938 1,437,000
1939 802,000
1940 1,844,000
1933-34 4,491,000
1933 131,000
1934 4,265,000
1935 5,385,000
1936 6,641,000
1937 5,418,000
1938 1,024,000
1939 500,000
1935 105,000
1936 8,453,000
1937 12,280,000
1938 95,000
1939 481,000
1934 715,000
1938 255,000
1939 140,000
1940 2,781,000
1943 38,000

Fig. 1--Atchafalaya River Basin, Louisiana

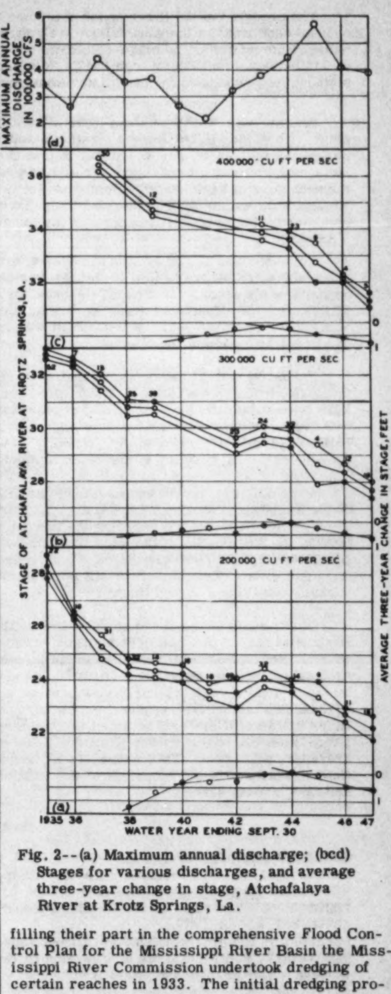

Fig. 2--(a) Maximum annual discharge; (bcd) Stages for various discharges, and average three-year change in stage, Atchafalaya River at Krotz Springs, La.

filling their part in the comprehensive Flood Control Plan for the Mississippi River Basin the Mississippi River Commission undertook dredging of certain reaches in 1933. The initial dredging program was later amplified so as to obtain a nearly continuous, well-defined channel from Mile 57 to Mile 100 in Grand Lake. The location by reaches, the year, and the cubic yardage of material moved are shown on Figure 1, [see MISSISSIPPI RIVER COMMISSION, 1932-1948].

The dredging of the lower reaches further accelerated the change in regimen so that in 1949 channel conditions of the Atchafalaya are yet to become stabilized. This fact is evinced by the study made by the writer of the stage-discharge relationship for the gage located at Krotz Springs (Mile 41.7) for the years 1935 through 1947. For this study, stage was defined as a measure of the resistance to flow caused by conditions downstream from the gaging station.

Inasmuch as the Atchafalaya is an alluvial stream the stage discharge relationship is not constant. This leads to obtaining a maximum and minimum stage for a given dishcarge in a given period of time. In a manner similar to that used by LANE [1937], Figure 2 (bcd) shows the maximum, minimum, and mean stage for discharges of 400,000, 300,000, and 200,000 cfs, respectively, for each year of gage record. Numbers, such as (22) for 1935 for 200,000 cfs, are the number of observations within 50,000 cfs of the base discharge. Figure 2 (a) shows the maximum discharge obtained by the river at Krotz Springs for the respective years.

An inspection of Figure 2 (bcd) reveals three pertinent points: (1) The initial dredging greatly reduced the resistance to flow in the reaches below Krotz Springs, thereby increasing the discharge capacity of the river at that point. (A one-foot increment of stage at 28 ft is equal to approximately 15,000 cfs.) (2) Continued dredging further increased the discharge capacity but at a decreasing rate. (3) During the years of low maximum discharge the rate of increasing capacity was retarded due to deterioration of the channel.

Points (2) and (3) can be visualized more readily be referring to the three-year average change in stage curves shown for each discharge. For a discharge of 200,000 cfs the first five years after 1935 show a definite decreasing rate of increase in capacity; then, the rate of increase remains relatively constant until the years of high maximum discharge bring about an increasing rate of increase in capacity owing to the "flushing" action of high discharges. Also, 2,678,000 cu yds were removed by dredging in the reach immediately downstream from the gaging station in 1947.

According to a recent announcement by CRAWFORD [1948] the next phase of the development of the Atchafalaya will soon be started. This will be: (1) Construction of a navigation lock at the Head of Old River thereby stopping the now unrestricted flow of the Mississippi toward the Atchafalaya; (2) the closing of the main line Mississippi River levee gap now present at the Head of Old River; and (3) construction of a control structure 15 miles upstream on the Mississippi from Old River. This structure will control diversion from the Mississippi at stages greater than bankfull (see Fig. 1, dotted lines).

On the basis of the above study of the available literature and data on the Atchafalaya River Basin it is feared that Matthes' third contention will be amply borne out by the Atchafalaya River when its separation from the Mississippi is completed. At that time the minimum discharge of the Atchafalaya will decrease from about 10,000 cfs to about 1000 cfs (from Red River). The sustained periods of high discharge now present will also be greatly shortened so that a combination of these two factors will enhance and encourage rapid channel deterioration of the entire Atchafalaya River system. Therefore, in times of maximum flood on the Mississippi the Atchafalaya will very likely be unable to convey the planned 600,000 cfs so that extremely high stages and probable levee crevasses will occur. This action, itself, could defeat the purpose of the comprehensive Flood Control Plan and leave the people of the Mississippi Valley with a severely, if not irreparably, damaged stream system.

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SALISBURY, E. F., Influence of diversion on the Mississippi and Atchafalaya Rivers, Trans. Amer. Soc. Civil Eng., v. 102, p. 75, 1937.

Gerard H. Matthes (Broadway Central Hotel, New York 12, N. Y., author's closure)--Halsey's discussion is of timely interest relating as it does to the Atchafalaya, this country's No. 1 Prodigy in stream channels. Originally a timber-obstructed, obscure bayou, it has grown into a large distributary channel of the Mississippi, and functions also as the outlet for the Red River. Not only has dredging played an important part in its enlargement but another factor has contributed, namely, as the levee system in the Mississippi River Valley grew progressively in height, flood stages also grew in height. The effect of levee confinement is shown by the fact that in the great flood of 1937, the inflow into the head of the Atchafalaya produced a stage 5-1/2 feet higher on the Simmesport gage than a comparable discharge in 1890, indicating steepening of the River's gradients.

The Atchafalaya is not a true river. It rates in potamology as a distributary or delta channel. As such, its alluviating propensities have been stupendous. With artificial aid its growth has been extraordinarily rapid. Halsey's contention to the effect that its channel is likely to deteriorate after perennial flow through Old River is blocked by control works, is well conceived. However, the future of the Atchafalaya is entirely in the hands of the engineers. The Atchafalaya's future channel capacity, after Old River is closed off, will depend on how much, and how often, water from the Mississippi River is permitted to pass through the proposed control works. Should this flow be insufficient for maintaining its existing channel capacity, Halsey's prophecy may well come true, for Red River water is rich in sediment and channel shrinkage due to deposition is a rapid process. However, the Red River also stages floods, at times of considerable magnitude. These can be capitalized upon to assist in part, at least, towards the maintenance of the Atchafalaya's channel. Furthermore, subsequent events will depend also on how much work is done towards improving the lower reaches of the Atchafalaya.

The author is indebted to Halsey for focusing attention on the Atchafalaya. Its past history has taught many valuable lessons, and its future history likewise promises to be of unusual interest.

DISCUSSION OF "THE LONG-TERM PRECIPITATION - RUNOFF RELATION AS THE BASIS FOR FORECASTING WATER SUPPLY" by MERRILL BERNARD

[Trans., v. 30, pp. 386-395, 1949]

H. G. Wilm (Pacific N. W. Forest Exp. Station, 423 U. S. Courthouse, Portland 5, Ore.)--During recent years it has been interesting to observe the accelerating interest in techniques for forecasting water yields, flood discharges, and other forms of streamflow. This is becoming an increasingly important field of endeavor for hydrologists, and the men who have concentrated on it deserve sincere credit for their accomplishments. A great deal of effort has obviously been put into the search for variables that are highly correlated with streamflow, and into the acquirement of graphic and statistical techniques for making forecasts. The results have appeared in these Transactions and other technical journals. Among the most advanced in technical progress are the papers by BERNARD [1949] and by KOHLER and LINSLEY [1949] which have put into published form the outcome of voluminous work by the United States Weather Bureau; other excellent examples are those by GARSTKA [1949] and by STANLEY and KENNEDY [1947].

Such publications give several pronounced impressions to the careful reader: that hydrologists are beginning to appreciate the great power of statistical methods as a tool in water-yield forecasting and related problems; that considerable advances have been made in their use; but that further success in the use of statistical methods will require additional study of the principles and logic underlying them.

This discussion will be devoted to the last of the above points. Without any reflection intended on the high quality of its contribution to hydrologic knowledge, Bernard's article will be used mainly for illustrations, with particular points drawn from other papers.

With reasonable precision, Bernard states that "both the slope and position of a regression line . . . . are subject to error because the few years used in the limited sample may prove to be poorly representative of events observed over a longer period of time" [p. 386]. This argument is well supported by data presented by Stanley and Kennedy. Where there is even a weak tendency toward time trends or cyclic variation, however, as illustrated by Garstka and by Kohler and Linsley, the use of long periods of record merely increases the amount of variation expressed as the residual variation around the regression line; and therefore the forecasts are likely to be lowered in precision.

Apparently none of the recent authors has fully appraised the logical or algebraic contents of forecasting errors. For very large "samples," the standard error of estimate supplies a sufficiently precise estimate of this error. But for the smaller numbers of observations which are commonly available in forecasting, this statistic must be combined with the sampling error of the forecasting equation itself [SNEDECOR, 1946]. The complete equation for the error of a forecast was first discussed in these Transactions by COOPERRIDER, CASSIDY, and NIEDERHOF [1945], following suggestions made by this writer and George W. Snedecor. Expressed more or less precisely in words, the forecast error is composed of the deviation of the actual new water yield from that point on the true regression line which corresponds to any assigned value of the independent variable (as precipitation), and the deviation of the corresponding point on the sample line from that point on the true line. The first of these is estimated statistically by the standard error of estimate; the second, by the standard error of the sample regression line.

Again, this highlights the fact that long records are not necessarily desirable; all that is needed is a record long enough so that the error of the sample regression line contributes a relatively small amount to the total error of the forecast.

In item (13), page 389, Bernard says "degrees of freedom have been conserved in a practical manner by" several rather subjective procedures. Actually what was done was to lose an indefinite number of degrees of freedom by employing a series of independent variables in preliminary adjustments. If any tests of significance or fiducial limits are to be established, it would seem desirable to make some reasonable estimate of the number of degrees of freedom that were actually consumed by these processes, perhaps equal to the number of independent variables in preliminary analyses.

The use of the quartile points (page 390) in making forecasts is excellent, and should continue to be useful in the development of forecasting procedures. On pages 390 and 392, however, are several inexact probability statements, which have evidently resulted from the study of past records alone as a basis for estimating the errors of forecasts. Take the first of these: "The observed flow will fall outside of the interquartile range in one half of the years of the ultimate record." Aside from any questions as to the validity of underlying assumptions (which are probably pretty sound, by the way), this statement is incorrect in two ways. First, the recorded median precipitation is a sample estimate of the true median of the "ultimate" population, and Bernard's statement applies only to the true median, though it will tend to fit the sample estimate better with increasing length of record. Second, even if it were true, this statement applies only to the independent variable, precipitation; there is an additional error in forecasting the "observed flow" from precipitation, which is estimated by the standard error of the forecast. Due to this component, half of the actual flows will fall above the "true flow" associated with precipitation at the upper quartile point, or below that for the lower quartile. Perhaps this is why the observed flow actually fell outside the maximum and minimum values even within the period of past records, without any real forecasts being involved (see Fig. 8-10, for example, page 393). Similar comments can be made, of course, about the statements on page 392; in actuality the cautious forecaster will not do quite as well as he claims.

One other error was made in connection with the quartile distribution. On page 392, the quartile values are not "equi-distant between the center and the extremes of the distribution." These values actually divide the frequencies above and below the average into equal parts; and therefore they lie substantially closer to the average than to the extreme values.

A number of statements accompanying Figure 7 are probably not precise because of the subjective nature of some of the preceding analyses, and only add complications to the concept of forecasting errors, especially through the stacking of percentages upon one another.

As to Figures 8-11 and the comments on them (page 394) there is nothing incorrect in the inclusion of a set of test years in the regression equation. The important thing is not to use the years within this set itself as a test of forecasting errors.

Perhaps the statements in the last paragraph on page 394 are safe. In a sound forecasting technique, however, assumptions such as these are not truly necessary. All that is needed is to keep the forecasting equation abreast of the times by predicting only one year ahead of the last year used in the analysis. When the resulting record becomes so long that the errors begin to grow again, this effect can be minimized by dropping off the earliest, obsolete years from the data used for each forecast, retaining only enough to insure adequate stability in the regression equation.

The above proposals may be thought to require large expenditures of time to keep the forecasting equation up to date for a number of watersheds. If, however, statistical short cuts are employed, especially those which make the most efficient use of electric calculators, the computation of "moving regressions" can be made in an easy and streamlined manner, new data being added and old ones removed in relatively few minutes per watershed. As an accessory feature, the analyst can watch for and remove the causes of unnecessary errors as they occur, and can detect the beginning of progressive shifts in runoff-precipitation relations.

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Merrill Bernard (U. S. Weather Bureau, Washington, D. C., authors' closure)--Wilm's constructive discussion calls for only a brief rebuttal, since many points are covered in a closing discussion by Kohler and Linsley in this issue (pp. 293-294). It is always difficult to justify less-than-exact methods, particularly when the presentation is made to a scientifically-minded reader-audience such as that of the American Geophysical Union. However, the author feels obliged to point out that his paper was an account of the development of a forecasting procedure to be used throughout the mountainous West, and which was dependent upon data poorly representative of area and topography. He cannot but yield to the temptation to say, "After all, it works." In the beginning of the development, all possible parameters and statistical refinements were tested. It was natural that those which did not contribute to the improvement of the correlations were abandoned in the light of the limited resources available.

Wilm suggests that "the use of long periods of record merely increases the amount of variation around the regression line; and, therefore, the forecasts are likely to be lowered in precision." It is, of course, a recognized fact that increasing the number of data increases the dispersion around a regression, but this does not reflect, necessarily, a lowering of forecast precision. If cyclical or time trends are present and are not corrected, forecast precision is lowered. On the other hand, a regression line based on only a few observations can be considerably in error, especially at extreme values. Whether a relation developed from 10 to 15 years of record is more reliable than one based on 35 or 40 years of adjusted data is certainly open to question. In addition, the use of a short period of record precludes the use of station or monthly weights which have been shown to markedly improve the correlations. The average record length of 30 years for both precipitation and stream flow does not seem to justify the designation of "very large samples," which might appropriately be applied to records two and three times as long. Certainly, there is evidence that in records shorter than ten or fifteen years little stability has been established in fixing the extremes and the distribution characteristics of the range between them. Consequently, it is difficult to see what advantage is to be gained by use of moving regressions until a substantially longer record period has accumulated.

Wilm's comments are correct in reference to the statement: "The observed flow will fall outside of the interquartile range in one half of the years of the ultimate record." The statement as made assumes true quartile values (not the sample) and perfect correlation between precipitation and runoff. Although the author's statement in his paper was misleading, the forecast user was informed of the approximation in the forecast bulletin as follows: "While it is known that the odds for the runoff values are not necessarily the same as those for precipitation, it has been found that they are sufficiently close to serve all practical purposes."

The author regrets the too-loosely stated explanation of the quartile values alluded to by Wilm. It is, of course, true that in a symmetrical distribution the quartile values are not equi-distantly spaced along the horizontal axis, but do divide the points controlling the shape and position of the curve into four groups of equal number.

DISCUSSION OF
"RECENT DEVELOPMENTS IN WATER SUPPLY FORECASTING FROM PRECIPITATION"
by R. K. LINSLEY, JR. and M. A. KOHLER

[Trans., v. 30, pp. 427-435, 1949]

Marvin Diamond (U. S. Bureau of Reclamation, Boulder City, Nev.)--The authors are quite correct in emphasizing the extreme importance of an estimated normal water supply to the planned economy of the semi-arid West. This has no doubt led to a considerable discussion of the runoff normals as published in the United States Weather Bureau forecast bulletins. The normal for the Colorado River at Lees Ferry for the years 1920-1944 as published in Weather Bureau forecast bulletins is 10.5 million ac ft (given as 11 million ac ft by authors). This compares with a normal of 12.7 million ac ft for the period 1922-1944 as computed from the published values of actual measurements by the United States Geological Survey. This difference in normals is quite appreciable, and since the Geological Survey normal is simply an average of measured values, the question arises as to why the Weather Bureau normal is so much lower.

I will compare the results of authors' procedure with results obtained in this office. A precipitation index based on 66 precipitation stations was developed by the authors for the entire area above Lees Ferry. The 66 stations came from a study of 16 headwater areas. Studies of precipitation stations in the Colorado Basin by this office reveal that there are only 35 stations which have nearly continuous precipitation records between 1913 and 1946 as follows: in Colorado, Collbran, Dillon, Fraser, Fruita, Glenwood Springs, Grand Junction, Palisade, Shoshone, Delta, Montrose, Gunnison, Paonia, Crested Butte, Steamboat Springs, Durango, Cedaredge, Pitkin, Ames, Cascade, Rico, Silverton, Telluride, and Trout Lake; in Utah, Emery, Vernal, Greenriver, Duchesne, Ft. Duchesne, Blanding, Moab, Price, Hanksville, and St. George; in Wyoming, Green River and Pinedale.

Therefore, the 66 stations selected by the authors must include a number of stations which are located outside of the basin. If runoff is to be adjusted on the basis of precipitation it would seem that it should be adjusted on the basis of the precipitation producing the runoff. Use of stations located outside a basin may result in erroneous conclusions unless it has been conclusively demonstrated that stations outside of the basin are in the same climatic regime as stations within the basin.

In our studies the average unadjusted precipitation of the 35 stations was used to represent the precipitation index for the Colorado River Basin above Lees Ferry, Arizona. No adjustments were made of any of the station records, because all parts of the basin did not contain stations which satisfied either of two consistency tests of MERRIAM [1937], and it was not possible to determine a standard precipitation pattern. A residual mass diagram (see Fig. 1) was constructed, using the 35 station average, to determine whether there was any decided change in the trend of the 35 station average. The resulting curve indicates no such change.

The average water-year precipitation of the 35 stations was correlated with the water-year runoff at Lees Ferry for the periods 1922-1946 and 1913-1946 (see Table 1).

Runoff was then computed for the period 1913-1946 and a double mass curve (see Fig. 2) was constructed for this period. This curve has three breaks; namely, at 1940, 1931, and 1924. The computed adjustments for the periods 1940-1931 and 1929-1924 are too small to be considered significant. The adjustment for the period 1923-1913 may be caused by the fact that the runoff values prior to 1922 are estimated.

With this in mind, runoff was then computed for the period 1922-1946 and a double mass

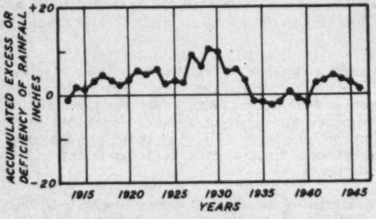

Fig. 1--Residual mass diagram; average water year precipitation of 35 stations in Colorado River Basin

Table 1--Correlation of precipitation and runoff

Period	Correlation coefficient	Forecast equation
1922-1946	0.6991	$Y = 1.01X - 2.14$
1913-1946	0.7014	$Y = 1.20X - 4.18$

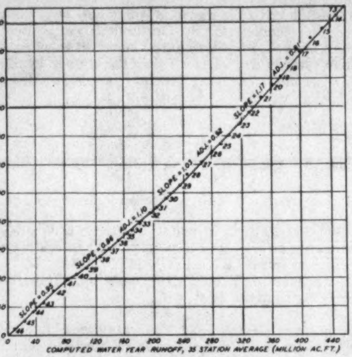

Fig. 2--Double mass plotting, Colorado River at Lees Ferry, Arizona, 1913-1946

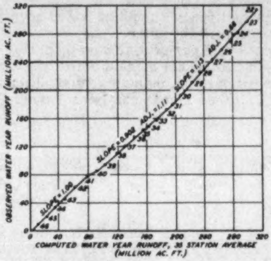

Fig. 3--Double mass plotting, Colorado River at Lees Ferry, Arizona, 1922-1946

curve (see Fig. 3) was constructed for this period. This curve has two breaks in it; namely, at 1940 and 1931. However, the computed adjustments for the periods 1940-1931 and 1930-1922 are too small to be considered significant. Examination of data on Table 2 shows that the breaks in the curve are caused by a succession of years in which the expected runoff was first more and then less than the observed runoff. The occurrence of such periods is probably due to chance.

As has been mentioned earlier, an estimated normal water supply is of great importance to the semi-arid west and for this reason any proposed radical change in previously published values

Table 2--Colorado River at Lees Ferry

Year	Observed water-year runoff	Computed water-year runoff[a]	Computed minus observed runoff
	million ac ft	million ac ft	million ac ft
1946	8.7	10.9	+ 2.2
1945	11.5	12.1	+ 0.6
1944	13.2	11.6	- 1.6
1943	11.2	14.0	+ 2.8
1942	17.0	13.3	- 3.7
1941	16.0	17.4	+ 1.4
1940	7.1	11.8	+ 4.7
1939	9.4	11.0	+ 1.6
1938	15.4	15.4	0
1937	11.9	12.9	+ 1.0
1936	11.9	12.3	+ 0.4
1935	9.9	12.1	+ 2.2
1934	4.4	8.3	+ 3.9
1933	9.7	10.4	+ 0.7
1932	15.2	13.1	- 2.1
1931	6.4	8.1	+ 1.7
1930	13.0	12.1	- 0.9
1929	19.2	16.4	- 2.8
1928	15.3	10.3	- 5.0
1927	16.5	18.9	+ 2.4
1926	14.0	12.5	- 1.5
1925	11.3	13.5	+ 2.2
1924	12.5	9.2	- 3.3
1923	16.2	13.6	- 2.6
1922	16.2	12.2	- 4.1

[a] Computed from correlation between water-year runoff, Colorado River at Lees Ferry and average water-year precipitation of 35 stations in Colorado River Basin above Lees Ferry

of normal runoff should be based upon thorough studies utilizing methods which can be proven to be conclusive. The authors' adjustment of earlier runoff records for the Colorado River at Lees Ferry by 74 per cent as based on their double mass curve, is questionable since this writer has shown that double mass studies based on a different number of stations than those used by the authors does not indicate any significant downward trend in the precipitation-runoff relation of the Colorado River near Lees Ferry.

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MERRIAM, C. F., A comprehensive study of rainfall in the Susquehanna Valley, Trans. Amer. Geophys. Union, pt. 2, pp. 471-476, 1937.

H. G. Wilm (Pacific N. W. Forest Exp. Station, 423 U. S. Courthouse, Portland 5, Ore.)--The authors are to be commended for the considerable efforts they have expended in testing variables that are correlated with runoff, and in attempts to improve the precision of water yield forecasts from precipitation data. This aspect of the forecasting problem is exceedingly important, and deserves all of the attention which is currently being given to it.

The following comments will supplement those made (see pp. 287-289, this issue) in connection with BERNARD'S [1949] paper, which deals with the same subject and procedures. Starting appropriately with the first paragraph, the writer can see no reasonable basis for concluding that it is useless to attempt comparisons of precipitation and snow-course records. Existing tests, however, have been weak, and much more powerful statistical testing tools are available. As an example, the correlation coefficient is not a strong criterion, as its size depends on the range of available data as well as on the magnitude of residual errors.

The techniques for adding "control" to the independent variable, described on pages 427-431, are ingenious but very laborious. Using regression coefficients as station or monthly weights may not actually contribute much; the coefficients are likely to be biased [EISENHART, 1939], and there may be a considerable degree of sampling error associated with them. Judging from Figure 4 in the paper by BERNARD [1949, p. 388], the use of monthly weights derived by this means helped to add precision in this particular example. Using a similar but what seems to be statistically sounder method, STANLEY and KENNEDY [1947, p. 768] made use of variations in precipitation between stations and months, with the result that "It has not been possible thus far to reduce forecast ranges by these processes." To the writer, it looks as though neither of these complex and laborious statistical methods is likely to give greater precision than some easier procedure like that of GARSTKA'S [1949] "elevation-weighting" of snow course data.

After all of the least-squares work leading up to this point, it seems remarkable that the authors should fit their final forecasting line by graphic methods [their Fig. 10 and discussion on p. 431]. A more logical procedure would be: (1) Decide on a rational basis whether the relation should be linear or curved, and the proper mathematical form for its expression; (2) if the basis of (1) seems uncertain, fit a straight line by least squares, and then fit curves of the second and higher degrees if necessary, testing each for significance; (3) calculate the forecasting equation; and (4) --this is, perhaps, the most important feature of all--calculate the necessary error statistics and the fiducial limits of the forecast, at any desired probability level.

In the first paragraph on page 432 is an inexact probability statement, similar to those in my discussion of Bernard's paper. Also, the assumption in the last sentence of this paragraph is incorrectly stated. A more exact phrasing would be "It is further assumed that, for any single assigned value of X, the observed flows will fall in a random and normally distributed manner around their mean." Note that no assumption is necessary about the random and normally distributed nature of the general population.

The procedure of fitting curves to the more recent data, illustrated in their Figures 8 and 12, is obviously weak and could be greatly strengthened by sounder analytic methods.

As suggested in the writer's discussion on Bernard's paper, a complete statistical technique for forecasting should be capable of detecting progressive time trends like those discussed on page 434, and of minimizing their effect on forecasts.

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M. A. Kohler and R. K. Linsley, Jr. (U. S. Weather Bureau, Washington, D. C., authors' closure)--The authors agree with Thomas that ground-water storage may in some cases be responsible for a change in the precipitation-runoff relationship. Although this item was not explicitly listed as one of the possible causes, changes in ground-water storage are closely related to trends in actual precipitation and it was this relation the authors had in mind [item 2 of "causes of time trends . . . ," p. 434].

The authors call attention to the fact that the United States Weather Bureau now publishes a normal annual flow of 11 million ac ft for Lees Ferry in accordance with the study cited in the paper. Moreover, 31 of the 66 stations used in the analysis are not located outside the basin as implied by Diamond. Actually only 17 of the stations are outside the drainage boundaries above the Lees Ferry station. However, some of the records used are composites of the data collected at two or more stations. That is, the early records for a discontinued station were combined with recent data from an existing station and the composite record so derived was adjusted by double-mass analysis. The authors do not agree with Diamond's statement that stations over the divide and just outside the basin proper should necessarily be omitted from the runoff adjustment analysis. His implication that the use of 35 stations (all within the basin boundaries) constitutes a comparison of runoff with a true measure of the precipitation producing it is erroneous. The average precipitation at the selected 35 stations can be considered nothing more than an index to the true average basin precipitation. This being the case, there is ample justification for including stations just outside the basin, provided they have value as an index to basin runoff. Those stations used in the author's analysis which lie outside the basin were selected because of their high correlation with runoff from some portion of the basin. Therefore, it seems to be conclusively demonstrated that they are "in the same climatic regime as stations within the basin" and it is hard to see how erroneous conclusions would result from their use.

Considerable care and judgment must be exercised in fitting line segments to double-mass plottings. The occurrence of one or two years in which the index or base is not representative can lead to false conclusions. In Figure 3 of Diamond's discussion, for example, he shows breaks at points labeled 31, 40, and 41. Examination of this plotting will reveal that the use of a single line segment from 31 to 46 would fit the points better except for 41 and 42. In other words, the 35-station average precipitation was a poor index to runoff in the years 1940 and 1942. That no break exists at 1941 is further substantiated in accompanying Figure 4 on which the data for 1947 and 1948 have been added by the authors. The plotting in this figure indicates that the records prior to 1931 should be adjusted by a factor of 0.79.

The assurance with which double-mass analysis can be applied to a particular problem depends upon the degree of correlation between the factors being related. If the factors are perfectly correlated except for a time trend, then the changes with time are readily determinable. Since the precipitation index developed by the authors in the original paper (based on 66 stations, weighted by months and stations) is more highly correlated with runoff than the 35-station average derived by Diamond, more significance must be attached to the results. The difference between the factors derived by the two analyses (0.79 and 0.74) is not appreciable, the principal question being whether the break should be at 1931 or 1934. The authors are nevertheless firmly convinced that both analyses indicate that the early records should be adjusted by a significant amount.

Diamond's statement that any revision of published normal runoff values should be based on thorough studies utilizing methods which can be proven to be conclusive raises the question as to what constitutes conclusive proof. The technique described has been shown to be reliable in cases where a definite break in record is known to have occurred. We can assume that it is also reliable where time trends are involved but only records yet to be accumulated can prove the correctness of the assumption. Whether an estimate of future average annual flow should be published as a nor-

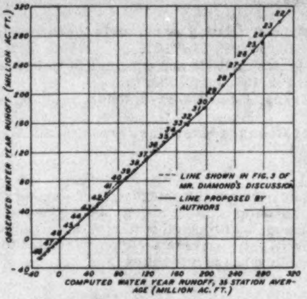

Fig. 4--Double mass plotting, Colorado River at Lees Ferry, Arizona, 1922-1946

mal flow might be questioned by some, but the authors believe that the study they have presented in the paper should at least cause those planning on a future average flow of 12.7 million ac ft at Lees Ferry to consider the possibility that it may be considerably less.

The introductory paragraph of the paper under discussion cited literature, some of which was devoted to a comparative analysis of precipitation and snow-survey data. In regard to such comparisons, the authors contend: (1) that comparative analysis of 10 or 15 years concurrent record from a single basin cannot constitute general proof that snow-survey data yield better forecasts of runoff than do precipitation data, or vice versa; (2) that, since climatic factors and relative density of the observational networks vary from area to area, it is possible to select a considerable number of basins for which analysis of available data will indicate either type of observation to be superior; and (3) that most effective use must be made of both types of data in any comparative study.

While the one statement in the introductory paragraph cited by Wilm is probably too general, the authors do not know what "more powerful statistical testing tools" he has in mind which will overcome these difficulties. It is believed Wilm's criticism of the correlation coefficient as a criterion is not applicable to comparative analyses when the data for the dependent variable are common to both correlations.

The two sentences immediately preceding that quoted from Stanley and Kennedy (in the paragraph of Wilm's discussion) are "In addition, multiple correlations with runoff, using precipitation occurring in each month as separate variables, have been made. Precipitation amounts occurring in various areas have been used as separate variables, as well as amounts occurring at various elevations." These statements so well describe the method used by the Weather Bureau (except for the attempted use of elevation) that it is hard to see what Wilm means when he states that Stanley and Kennedy used "what seems to be a statistically sounder method." With regard to the preferred use of "some easier procedure like that of Garstka (1949) elevation weighting of snow course data," it should be pointed out that there are a number of factors other than elevation which should be considered in any arbitrary weighting procedure, the more important being areal distribution, slope and aspect. Whether all factors can be better accounted for in an arbitrary weighting system than by multiple correlation is certainly questionable.

The authors find no particular fault with Wilm's suggested outline of steps to be followed in determining the final forecasting relation, provided all verification is to be on a standard-error basis. However, we have every reason to believe that most users tend to average the forecast errors and, in this event, a curve fitted to group mean-points would be better than a least-squares forecasting relation. It should be realized that there is very little difference in the two, however, when the degree of correlation is high.

LETTERS TO THE EDITOR

BOOKS ON HYDROLOGY

During the past year five new textbooks on the subject of hydrology have been published. We are accustomed to textbooks in the older sciences like astronomy, geology, and meteorology, but hydrology is as yet new and workers in this field have generally relied upon the Transactions of the AGU for information on theories and principles. However, a number of eminent hydrologists apparently have almost in unison discerned a lack of modern textbooks on hydrology.

The first hydrology textbook in English known to the writer is that by Beardmore, published in London in 1862, which was a very useful source of information about climate, the flow of rivers, hydrography, evaporation, and practical hydraulics. Incidentally the form of monthly table used to report stream flow data is almost exactly like that now used by the U. S. Geological Survey. An up-to-date revision of Beardmore's text would, I am sure, be a very useful compendium. There is a gap until 1904 when D. W. Mead issued his Notes on Hydrology which he followed up by a formal text in 1919, about the same time A. F. Meyer published his Elements of Hydrology. These two later texts have served in the training of many hydrologists as well as a source of information for practitioners for many years and still are very useful. From 1919 to 1942, three new textbooks appeared, including that edited by O. E. Meinzer, under the sponsorship of the National Research Council. Thus up to 1942 there were seven books available. The past year has nearly doubled this number. What meaning does this spate of books have in the development of the science? The writer hopes that it will lead to wider teaching of hydrology in the colleges.

I have listed below the titles of 12 English-language textbooks on hydrology. The list does not include books dealing with specialties such as Tolman's Ground water, Kittredge's Forest Influences, or C. S. Fox's Geology of Water Supply.

BEARDMORE, NATHANIEL, Manual of hydrology, Waterlow and Sons, 384 pp., 18 pl., London, 1862.

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MEINZER, O. E., (editor), Hydrology, Physics of the Earth, pt. 9, McGraw-Hill, 712 pp., 1942, reprinted by Dover Publications, 1949, ($4.95).

FOSTER, E. E., Rainfall and runoff, Macmillan, 487 pp., 1948 ($9).

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AMERICAN SOCIETY OF CIVIL ENGINEERS, Hydrology manual, Manuals of Engineering Practice, no. 28, 184 pp., 1949 ($1.50 to members ASCE, $3.00 to others).

WISLER, C. O., and BRATER, E. F., Hydrology, John Wiley, 419 pp., 1949 ($6.00).

LINSLEY, R. K.; KOHLER, MAX A.; PAULUS, JOS. L. H., Applied hydrology, McGraw-Hill, 689 pp., 1949 ($8.50).

W. B. Langbein

U. S. Geological Survey, Washington 25, D. C.
November 18, 1949

CORRECTION IN REFERENCE CITATION

There has been called to the attention of the authors of the paper "Use of Shoran in Geodetic Control," [Trans., v. 27, pp. 459-463, Aug. 1946], an incorrect reference in the brief discussion dealing with reduction from spherical to spheroidal angles [p. 462]. As indicated by the reference given, Eq. (5) originated in Tobey's development. The exact form, however, was based on a transformation, properly referenced, by H. F. Rainsford in his article, "The Clarke Formulae for Latitude, Longitude and Reverse Azimuth, with Corrective Terms for Use on Very Long Lines," [Empire Survey Rev., v. 8, no. 56, Eq. (21), p. 60, 1945]. This paper clarifies and extends the work of A. R. Clarke and W. M. Tobey on the subject of large spheroidal triangles. The reference cited by the author should have been Rainsford rather than Tobey. The authors regret this oversight.

Subsequent to publication of the Shoran paper, Rainsford's formula was further transformed, using the original notation, as follows

$$\tau\overset{\prime\prime}{\lambda} = -[(\sin^2\phi_m - \sin^2\phi_A)\epsilon'' e^2]/6$$

The above formula was found somewhat more convenient for use with computing machines.

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U. S. Coast and Geodetic Survey, Washington 25, D. C.
December 6, 1949

Transactions, American Geophysical Union Volume 31, Number 2 April 1950

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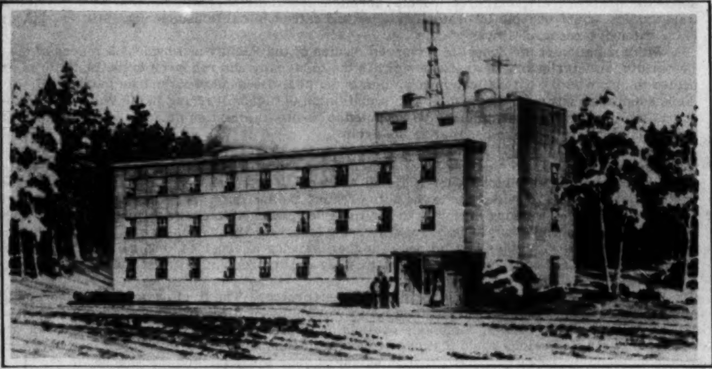
NOTES AND PERSONALIA

NOTES

University of Alaska, Geophysical Institute--The Geophysical Institute at the University of Alaska had its origin in 1929 when a grant from the Rockefeller Foundation established the means for studies of auroral heights. During the International Polar Year of 1932-1933, the University of Alaska was designated a first order station in the network engaged in seismological, terrestrial magnetic, electric potential measurements, auroral investigations, and study of the ionosphere. From 1934 to 1941 a portion of the Polar Year program was continued.

In 1941 a cooperative research endeavor was inaugurated by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, and the University of Alaska directed towards an exact and systematic study of the ionosphere, oblique incidence radio wave propagation, and the Earth's magnetic field variations. The seismological work was continued for United States Coast and Geodetic Survey.



New building of the Geophysical Institute. University of Alaska

With advent of World War II the program was expanded to include study of deviation of radio waves from the great circle course, rapid fluctuations of the magnetic field, measurement of auroral light intensity variations, and a program of illumination measurements for the Weather Bureau.

This elaborate program continued through 1946 at which time the Carnegie Institution of Washington withdrew from military research. As much of the program had important scientific merit, however, the University continued the ionospheric, signal intensity, magnetic, and seismological work on a contract basis with the National Bureau of Standards, the Coast and Geodetic Survey, and by means of equipment loaned principally by the Carnegie Institution and the contracting agencies. A small study of atmospheric refraction was also undertaken for the Navy Department.

Meanwhile the University proposed, through the Delegate from Alaska, that the Congress grant funds to establish at the University a permanent Geophysical Institute devoted to research in the arctic in the field of natural science. This legislation was supported by essentially every government department and by eminent scientific agencies and individuals. While the bills to establish such a Geophysical Institute were pending, the University in April 1948 established an interim organization, called the Geophysical Observatory, in order to create a program and assemble a staff for arctic geophysical research to become the program and staff of the Geophysical Institute. To this end the formal organization and plans for formation of the Geophysical Institute were completed. The seismological and magnetic programs were transferred to the United States Coast and Geodetic Survey Observatory on the campus.

The Congress approved establishement of the Geophysical Institute and appropriated $975,000 for construction. Construction is being done by the Federal Works Agency, Public Buildings

Administration. The total floor area of the new building is 19,000 sq ft plus an observing deck of 6000 sq ft. There is a penthouse with six removable hatches in the roof, two ceolostat piers with associated tubes leading below, an astrodome for the telescope, and pipe sleeves from the roof deck to every laboratory on the floor below. The building will accommodate a maximum personnel of 75 which with a potential of ten at the field stations will bring the estimated maximum staff to 85. Six dwellings for scientists are included in the construction.

Occupancy is scheduled for June 1950. Until completion of the buildings, the Geophysical Institute, formally established July 1, 1949, is housed temporarily in adjacent University buildings. The Territorial Legislature included in its biennial University budget $115,000 for the basic requirements of the Institute for the interval July 1, 1949 through June 30, 1951. In addition to the facilities and equipment in full use there is additional equipment for astronomy with a ten-inch reflecting telescope; for meteorology with simple standard equipment; for low ambient temperature research on snow, ice, and fog with easily fabricated instruments; for laboratory and field measurements of impedances, reactances, and resistances; for studies of compressional wave propagation; and for other work. The Institute also operates six outlying field stations ranging in distance to 25 mi. There will also be available a considerable computing service, an instrument shop with machine tools, dust proof rooms, chemical laboratories, isolated pillars for gravitational field studies, spectroscopic laboratories, solar and astronomical telescope possibilities, and a more more extensive research library.

With formation of the School of Advanced Studies of the Faculty of Physical Sciences at the University, an interlocking of graduate work in the University and research in the Institute is expected to occur as the natural common ground is defined. Because of its unique location within the academic structure of the farthest north institution of higher learning in the Western Hemisphere, the Geophysical Institute may be expected to devote its attention principally to research in the fields of natural science peculiar to the arctic.

General administration is from the President of the University to the Director of the Institute to the section chiefs at the working level. Scientific matters are decided by the Council of Fellows of the Institute. The President of the National Academy of Sciences reviews the general program from time to time as provided for in the acts creating the Institute. A policy of inviting younger scientists to become working members of staff has been adopted in order to achieve the necessary conditions for versatility of attack. A plan is being inaugurated for exchange of graduate students and staff members with other institutions of higher learning in order to keep the staff broadly informed, and to afford opportunity for others to study arctic problems at first hand.

Publication of bibliography and abstracts in meteorology--The first number of Meteorological Abstracts and Bibliography, issued by the American Meteorological Society, was published under date of January, 1950. This is a monthly publication sponsored by the Geophysical Research Directorate of the Cambridge Field Station, Air Materiel Command, U. S Air Force, and presents an annotated bibliography gathered from 36 scientific journals published throughout the world. Interested persons should write to the American Meteorological Society, 5 Joy Street, Boston 8, Massachusetts.

New course in fuels resources--Rensselaer Polytechnic Institute has announced a new four-year curriculum in Fuels Resources to begin in September, 1950, offering instruction and research at the graduate level, also. Courses will embrace the economics as well as the science and technology of all types of fuels. Roland F. Beers has been appointed Professor of Geophysics and Head of the new Department, and will be assisted by Shepard W. Lowman, until recently Research Stratigrapher with the Shell Oil Company. Guest lecturers will be William B. Heroy and Isaac Arnold. The philosophy behind the establishment of the Department is the encouragement of industries to realize the wisdom of a broader base of fuel supply than the customary single one.

Opportunities under the Fulbright Act--Opportunities for foreign study and teaching under the Fulbright Act will soon be extended to include Australia, Egypt, Iran, Turkey, and India, as agreements have been signed with these countries, though programs have not yet been initiated. This will bring the total number of countries operating programs under the provisions of this Act to 16. Those with programs already in operation are United Kingdom and British Colonial Dependencies, Belgium, Luxembourg, France, Greece, Italy, the Netherlands, Burma, the Philippines, New Zealand, and Norway. Under this Act, arrangements may be made for the payment of the travel of foreign scientists and educators to the United States as well as the payment of the expenses of citizens of the United States on similar missions abroad. All payments are in the currency of the foreign country, with no payments in dollars. Applications are now being received for the year 1951-1952. For the current year, there were about 1500 applications for the 250 openings that were available. It is anticipated that there will be more openings in the coming year. Interested persons should write to the Committee on International Exchange of Persons, Conference Board of

Associated Research Councils, 2101 Constitution Avenue, Washington 25, D. C.

Summer courses in Climatology--Massachusetts Institute of Technology is offering two six-week programs in Climatology, the first from June 12 to July 21, 1950, and the second from July 24 to September 2, 1950. The staff for the eight courses offered will include Woodrow C. Jacobs, Helmut E. Lansberg, and Heinz H. Lettau. Inquiries should be addressed to the Director of the Summer Session, Room 3-107, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

Atomic Energy Commission scholarships--The Atomic Energy Commission is offering 244 pre-doctoral fellowships in the physical and biological sciences during the next academic year. Under current regulation, all successful applicants will be subject to FBI investigation. The fellowship program is being administered by four regions: Northeast, Associated Universities, Inc., Room 1611, 393 Seventh Avenue, New York, N. Y.; Southeast, Oak Ridge Institute of Nuclear Studies, Inc., Oak Ridge, Tennessee; Midwest, Argonne National Laboratory, University of Chicago, Chicago, Illinois; and West, University of California, Berkeley, California. All applicants in the physical sciences shall have one year of work beyond their baccalaureate degree. This is in addition to the program of 250 AEC fellowships being administered by the National Research Council, Washington 25, D. C.

International Scientific Radio Union (URSI) to meet in Zurich--The Ninth General Assembly of the International Scientific Radio Union will be held in Zurich, Switzerland, September 11-23, 1950. The American National Committee of the Union held two spring meetings, one in San Diego during the week of April 3, 1950, and the other in Washington, April 17-19, 1950. Persons interested in any of these meetings should get into touch with Newbern Smith, Secretary of the USA National Committee, National Bureau of Standards, Washington 25, D. C.

World Petroleum Congress to be held in the Netherlands--The Third World Petroleum Congress has been tentatively scheduled to be held in The Hague, the Netherlands, May 28 to June 6, 1951. This will be the first one since the war. The First Congress was held in London in 1934; the Second in Paris in 1937.

PERSONALIA

Keith E. Anderson has resigned his position as Geologist with the Iowa Geological Survey, and accepted an appointment as Geologist with the U. S. Bureau of Reclamation with headquarters at Salem, Oregon.

Norman F. Braaten, Mathematician with the U. S. Coast and Geodetic Survey, was recently awarded the Meritorious Service Medal of the Department of Commerce.

Randolph W. Chapman, Professor of Petrography at Johns Hopkins University is Visiting Lecturer in Geology at St. Andrews University, Scotland, under the provisions and program of the Fulbright Act.

Leo O. Colbert, Chief, U. S. Coast and Geodetic Survey, has been given the Exceptional Service Award of the Department of Commerce.

Lindsay P. Disney, Chief of the Section of Predictions, Division of Tides and Currents, U. S. Coast and Geodetic Survey, has been given the Meritorious Service Award of the Department of Commerce.

Robert E. Gebhardt, Geophysicist with the U. S. Coast and Geodetic Survey, has recently been given the Meritorious Service Award of the Department of Commerce.

Seymour L. Hess of Lowell Observatory has accepted an appointment as Associate Professor in the Department of Meteorology, Florida State University, effective at the beginning of the academic year 1950-1951.

Edward Hyatt, State Engineer of California, has retired after 35 years of service with the State. He has been succeeded by Arthur D. Edmonston who was Deputy State Engineer.

C. O'D. Iselin, Director of Woods Hole Oceaonographic Institution has resigned in order to devote his full time to scientific research. He will divide his time between work at the Institution where he will be Senior Oceanographer, and Harvard University where he will be Associate Professor of Physical Oceanography. He has been Director since 1940. A special committee has been designated by the Trustees to select a successor.

Carl F. Izzard, in charge of hydraulic and hydrologic studies for the Bureau of Public Roads, has been awarded the Meritorious Service Medal of the Department of Commerce.

Harold E. McComb, Chief of the Geomagnetism Branch of the U. S. Coast and Geodetic Survey, has been given the Exceptional Service Award and the Length of Service Award of the Department of Commerce.

Elmer C. McKay, Mathematician with the U. S. Coast and Geodetic Survey, has been given the Meritorious Service Medal of the Department of Commerce.

John S. McNown, Assistant Professor and Research Engineer of the Iowa Institute of Hydraulic Research, has recently been named first recipient of the Research Program Prize of the American Society of Civil Engineers for his project outline, "Fundamental Research in Sediment Transportation."

Jerome Namias, Chief of the Extended Forecast Section of the Weather Bureau, has been a awarded the Meritorious Service Medal of the Department of Commerce.

Frank Neumann, Chief of the Seismological Branch of the U. S. Coast and Geodetic Survey, has been awarded the Meritorious Service Medal of the Department of Commerce.

W. Armstrong Price, Consulting Geologist of Corpus Christi, Texas, has been appointed Professor in Geological Oceanography in the new Department of Oceanography of the graduate school of the Agricultural and Mechanical College of Texas.

Francis W. Reichelderfer, Chief, U. S. Weather Bureau, has been given the Exceptional Service Award of the Department of Commerce.

Frederick Sanders has obtained leave from his work with the U S. Weather Bureau, and has accepted a Research Assistantship and is at the same time pursuing graduate studies in meteorology at the Massachusetts Institute of Technology.

Stephen S. Visher, Professor of Geography, Indiana University, currently President of the Indiana Academy of Science, is preparing a biographical directory of Indiana Men of Science in which he plans to include all scientists who have been born, received their college education or who worked in Indiana. The volume is being prepared under the auspices of the Academy.

Curt H. Eiffert, Chief Engineer and General Manager of the Miami Conservancy District, died on February 3, 1950 after an illness of six months. He was born at West Side, Iowa, in 1883, and received his baccalaureate degree from Cornell College (Iowa). He devoted the early part of his career to railroad, drainage, and land-surveying problems in the Great Plains region and other parts of the Middle West, and from 1911 to 1915 on work in Illinois. He entered the services of the Miami Conservancy District while that was in the planning and construction phases in 1915, and became Chief Engineer and General Manager in 1924.

Richard Charles Farrow, Comptroller of Water Rights, Department of Lands and Forests of British Columbia, died suddenly February 20, 1950 just after returning from a Snow Conference at Sun Valley. He was born in England in 1892, and in 1909 passed the preliminary licensed surveyor's examination in British Columbia, and began work with Humphrey and Tupper, licensed surveyors and engineers of British Columbia. He continued his work in British Columbia until 1923, except for four years of service in World War I. From 1923 to 1928, he worked with the Southern California Edison Co. in various water power and civil engineering work. In 1928, he returned to British Columbia to take up duties in the Water Rights Branch of the Department of Lands and Forests, which he continued until his death, except for a tour of duty as consulting engineer in England in 1933 and 1934, and service in Europe during World War II, during which he attained the rank of major. At the time of his death, he was Chairman of the AGU Committee on Snow, in which field he had worked actively in British Columbia and the West in initiating and studing problems of snow surveying. He had been a member of AGU since 1937.

Raymond W. Pierce, Hydraulic Engineer with the Corps of Engineers in Atlanta, died September 22, 1949. He was born at Howell, Michigan, April 29, 1910. He received his baccalaureate degree from the University of Michigan in 1931, and master's degree in 1933. He subsequently worked with the Forest Service on hydrologic problems, and in 1942 began his work with the Corps of Engineers.

Innokenty Pavlovich Tolmachoff, Curator of Geology and Paleontology, retired, of the Carnegie Museum of Pittsburgh, died January 17, 1950, at the age of 77. He was born at Irkutsk, Russia, receiving his collegiate education at the University of St. Petersburg and the University of Munich. He became Assistant Professor of Geology at Dorpat University in 1897, and was Curator of Geology, Russian Academy of Sciences in St. Petersburg from 1899 to 1913, and Chief Curator from 1913 to 1920. From 1920 to 1922, he was Professor of Geology and Paleontology at the Far East Polytechnic Institute in Siberia. From 1922 until his retirement in 1946, he was engaged in work at the Carnegie Museum. Both in Russia and the United States, he devoted various periods to special assignments. He had been a member of AGU since 1935.

UNION, SECTION, AND COMMITTEE ACTIVITIES

Twenty-Fifth Regional Meeting--The Twenty-Fifth Regional Meeting of AGU was held at the University of California at Davis, February 3-4, 1950. About 200 registered, but many staff members in addition were in attendance. The Sections of Meteorology and Hydrology only held sessions, but they were joined by an informal Evaporation Conference that had held a meeting in Los Angeles in September, 1949 also. Thirty-three papers were presented at the six sessions and the evening meeting The session on the morning of February 3 and the afternoon of February 4 were joint sessions of all groups. The Section of Meteorology and the Section of Hydrology had separate sessions on the afternoon of February 3. On the morning of February 4, the Section of Hydrology held a joint session with the Evaporation Group, and the Section of Meteorology met alone. On the evening of February 3, there was a dinner for all groups followed by an illustrated talk by S. H. Marsteller on Radar Observations of Raihfall. F. J. Veihmeyer was the General Chairman of the Meeting. For the Section of Hydrology, matters were handled by J. C. Marr, J. W. Johnson, and C. N. Johnston; for the Section of Meteorology, E. M. Vernon, J. H. Marsteller, and R. C. Counts, Jr.; and for the Evaporation Conference, F. A. Brooks, L. M. K. Boelter, and H. F. Poppendiek.

SPECIAL ANNOUNCEMENT

Bibliographies in the Transactions--The bibliographies currently published in the *Transactions* are prepared by the members of the Editorial Committee and from exchange publications. No effort is made to include all items but rather those from foreign publications, and ones that might be easily overlooked. The bibliographies are necessarily incomplete because of space, time, and financial limitations. The Editorial and Publication Committee is considering the advisability of eliminating the bibliographies because it is believed that the space may be more useful for publication of additional scientific and technical papers. In some of the fields of geophysics there are very complete bibliographies available, and in all fields there are a number of sources of bibliographic material. Possibly it may be advisable to retain the bibliographies in fields not adequately covered elsewhere. However, the whole question depends on the value of the bibliographies, as presently published, to the readers of the *Transactions*. This can be determined only by an expression of opinion by a fairly large and representative group of readers. The Editorial and Publication Committee therefore requests that you fill in and return the subjoined form. Letters giving opinions and suggestions in greater detail will be appreciated.

I am especially interested in ☐ Geodesy, ☐ Seismology, ☐ Meteorology, ☐ Terrestrial Magnetism and Electricity, ☐ Oceanography, ☐ Volcanology, ☐ Hydrology, ☐ Tectonophysics.

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TRANSACTIONS
AMERICAN GEOPHYSICAL UNION

Volume 31 APRIL 1950 Number 2 Part 2

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PROGRAM

THIRTY-FIRST ANNUAL MEETING

In the Building of the National Research Council - National Academy of Sciences,
the Auditorium of the General Services Building,
and the Interdepartmental Auditorium
Washington, D. C.

May 1-3, 1950

SCHEDULE OF SESSIONS

Monday, May 1, 1950

$09^{h}00^{m}$ METEOROLOGY--Room 1 VOLCANOLOGY--Room 2
HYDROLOGY--Room 3
$14^{h}00^{m}$ GEODESY--Room 2 METEOROLOGY--Room 3
HYDROLOGY--Room 1
$20^{h}00^{m}$ EVENING SESSION (Presidential Address, Award of the William Bowie Medal, Social Hour--Room 2

Tuesday, May 2, 1950

$09^{h}00^{m}$ SEISMOLOGY--Room 1 OCEANOGRAPHY--Room 3 TECTONOPHYSICS--Room 2
METEOROLOGY and HYDROLOGY (with American Meteorological Society)--Room 4
$14^{h}00^{m}$ TERRESTRIAL MAGNETISM AND ELECTRICITY--Room 2 HYDROLOGY--Room 1
$20^{h}00^{m}$ SMOKER--Auditorium of the Cosmos Club, Madison Place near H Street, Northwest

Wednesday, May 3, 1950

$09^{h}00^{m}$ TERRESTRIAL MAGNETISM AND ELECTRICITY--Room 2
OCEANOGRAPHY--Room 1 TECTONOPHYSICS (including papers bearing on Seismology)--Room 3
$14^{h}00^{m}$ GENERAL ASSEMBLY: Special Program and Business Session--Room 1

(For key to room numbers, see page 322)

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Hyurology	Lorenz G. Straub	F. J. Veihmeyer	Ray K. Linsley, Jr.
Tectonophysics	M. King Hubbert	Robert Balk	Wilbur S. Burbank

GENERAL MEETINGS OF THE UNION

EVENING SESSION

Monday, May 1, 1950, 20^{h}00^{m}, Room 2 (Lecture Room, National Academy of Sciences)

Presidential Address
- WALTER H. BUCHER: Megatectonics and geophysics

Twelfth Award of the William Bowie Medal
- (a) Citation by Leo Otis Colbert, Chairman of the Committee on the Award
- (b) Presentation by Walter H. Bucher
- (c) Acceptance

Social hour and refreshments

SMOKER

Tuesday, May 2, 1950, 20^{h}00^{m} to 22^{h}00^{m}, Auditorium of the Cosmos Club,
Madison Place near H Street, Northwest

This will be an informal get-together. No program has been planned. Refreshments will be served. Tickets are 75 cents, and will be sold in advance at the Main Registration Desk in the Building of the National Research Council - National Academy of Sciences, and by the Secretaries of the Sections. Ladies are invited.

GENERAL ASSEMBLY: SPECIAL PROGRAM AND BUSINESS MEETING

Wednesday, May 3, 1950, 14^{h}00^{m}, Room 1 (Auditorium, National Academy of Sciences)

Special Program
- (1) U. S. Naval Operations in Alaska (color-sound cinema)
  - (a) Exploration for oil, showing adaptation of geophysical exploration methods to arctic conditions
  - (b) Construction, showing problems encountered in permafrost regions and how they have been met
- (2) Oil fog tests at Brookhaven National Laboratory, time-lapse cinema of the turbulent diffusion of an oil fog emitted from a 355-ft chimney during stable and unstable atmospheric conditions with commentary by Philip H. Lowry
- (3) DAVID M. DELO: Program and aims of the American Geological Institute

Business Meeting
- (1) Reports of officers and of special and standing committees, including:
  - (a) General Secretary's report
  - (b) Report of the Committee on Resolutions (Earl Ingerson, Chairman; J. P. Marble, and C. F. Brooks)
- (2) Unfinished business
- (3) New business

MEETINGS OF THE SECTIONS

SECTION OF GEODESY

Monday, May 1, 1950, $14^{h}00^{m}$, Room 2 (Lecture Room, National Academy of Sciences)

Business Session
Reports of committees and other business
Scientific Session
(1) JOHN A. O'KEEFE: The application of tensor analysis to certain problems in geodesy
(2) FLOYD W. HOUGH: International cooperation on a geodetic project
(3) DONALD A. RICE: Report on determination of deflections of the vertical from gravity anomalies
(4) LLOYAL O. BACON: Gravity surveys of central Pennsylvania (by title)
(5) GEORGE P. WOOLLARD: A reconnaissance gravity survey of the Island of Oahu
(6) MAURICE EWING and J. LAMAR WORZEL: Gravity measurements at sea; Part I, 1948; Part II, 1949
(7) PAUL C. WUENSCHEL: Gravity measurements in South America, 1948, preliminary results
(8) ALBERT J. HOSKINSON: Harmonic analysis of gravity observations
(9) CARL I. ASLAKSON and OMAR O. FICKEISSEN: Effect of meteorological conditions on measurements of long distances by electronics
(10) MANUEL MEDINA: Geodetic work in Mexico from June 1949 to April 1950 (by title)

SECTION OF SEISMOLOGY

Tuesday, May 2, 1950, $09^{h}00^{m}$, Room 1 (Auditorium, National Academy of Sciences)

Business Session
Reports of committees and other business
Scientific Session
(1) JAMES B. MACELWANE: Progress report for the Jesuit Seismological Association for 1949 (5 minutes)
(2) H. BENIOFF, B. GUTENBERG, and C. F. RICHTER: Progress report, Seismological Laboratory, California Institute of Technology, 1949 (20 minutes)
(3) M. A. TUVE and H. E. TATEL: Seismic observations, Corona (California) blast, 1949 (20 minutes)
(4) J. N. NANDA, H. E. TATEL, and M. A. TUVE: Prolonged seismic wave reception: Interpretation as scattered waves (20 minutes)
(5) JUDSON MEAD: Preliminary results of deep crustal reflection studies (10 minutes)
(6) J. JOSEPH LYNCH: An investigation of two-second microseisms associated with cold fronts and a new method for tracking the center of the latter (15 minutes)
(7) MARION H. GILMORE and C. W. GOYDER: Storm microseisms: A note on their origin, propagation, and measurement (20 minutes)
(8) ANDREW A. THOMPSON: Seismographic work on Palmer Peninsula, Antarctica (20 minutes)
(9) ELLIOT B. ROBERTS: Development of a seismic-wave warning service for Hawaii (10 minutes)
(10) JOSEPH A. VOLK: The pulse magnetic seismograph (10 minutes)
(11) P. M. HONNELL: The absolute calibration of a brush accelerometer and its response to square waves of displacement and velocity (15 minutes)
(12) EDWARD F. CAROME: An electronic vibration meter (10 minutes)

SECTION OF METEOROLOGY

Monday, May 1, 1950, $09^{h}00^{m}$, Room 1 (Auditorium, National Academy of Sciences)

Business Session
Reports of committees and other business
Scientific Sessions
Atmospheric Physics
(1) GEORGE S. BENTON: Meridional transport of water vapor in the atmosphere
(2) W. S. WILSON: Surface ozone determination at College, Alaska

(3) **SIGMUND FRITZ:** Ozone observations at Washington, D. C.
(4) **C. L. HOSLER:** Preliminary investigation of condensation nuclei under the electron microscope
(5) **H. G. HOUGHTON:** A preliminary quantitative analysis of precipitation mechanisms
(6) **DUNCAN C. BLANCHARD:** The behavior of large waterdrops at terminal velocity
(7) **J. VERN HALES:** Meridional cross sections of radiational heat losses due to water vapor

Monday, May 1, 1950, 14^h00^m, Room 3 (Auditorium, General Services Building)

Meteorological Measurements and Instruments
(8) **H. H. LARKIN, JR. and B. L. WIGGIN:** Time-lapse motion pictures of the whole sky as an observational tool
(9) **ARNOLD WEXLER:** Humidity test apparatus, recirculating type
(10) **J. B. MACELWANE and W. F. SPRENGNETHER, JR.:** A portable nephometer
(11) **GEORGE S. BENTON and WINTON COVEY:** Measurement of meteorological variables by use of multiple energy balance indicators
(12) **J. SHERROD, H. NEUBERGER, and D. YERG:** New standards for Landsberg's glass-rod method of integrating ultraviolet radiation
(13) **WILLIAM D. MURRAY, CHARLES S. SCHNEIDER, and JAMES R. SMITH:** Development and utilization of constant-level balloons
(14) **J. DOYNE SARTER, ISADORE KATZ, and ROBERT KATZ:** A method for the measurement of atmospheric diffusion at intermediate levels using mobile equipment
(15) **V. J. SCHAEFER:** The formation, growth, and dissipation of clouds in the free atmosphere

Tuesday, May 2, 1950, 09^h00^m, Room 4 (Interdepartmental Auditorium Conference Room B)

(Jointly with the Section of Hydrology and
the American Meteorological Society)

Hydrometeorological Problems
(1) **MERRILL BERNARD:** Hydrometeorological phases of the water-resources problem
(2) **THEODORE W. KLEINSASSER:** Meteorological factors affecting the operation of multiple-purpose hydrologic structures
(3) **D. B. KRIMGOLD:** Erosion and precipitation (by title)
(4) **MARTIN A. MASON:** The wind element in beach erosion
(5) **VINCENT J. SCHAEFER:** The formation of frazil ice and anchor ice in cold water
(6) **FRANKLIN F. SNYDER:** Meteorological factors in hydrologic design
(7) **JOSEPH V. B. WELLS and CONRAD D. BUE:** The water supply in United States

(Note: The sessions of the American Meteorological Society continue Tuesday afternoon, May 2, and all day Wednesday, May 3, with headquarters in the Interdepartmental Auditorium Conference Room B. See the program of the American Meteorological Society for the Tuesday afternoon and Wednesday schedule. In arranging the above program and that of the American Meteorological Society, some papers submitted to the American Geophysical Union for its program have been transferred to the program of the American Meteorological Society, in the interests of unity of program content. Likewise, some papers submitted to the American Meteorological Society have been transferred to the program above.)

SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

Tuesday, May 2, 1950, 14^h00^m, Room 2 (Lecture Room, National Academy of Sciences)

Business Session
Reports of committees and other business
Scientific Sessions
(1) **JOHN W. GRAHAM, O. W. TORRESON, and EDGAR BOWLES:** Magnetic polarizations of Silurian sediments of the eastern United States (15 minutes)
(2) **M. W. JONES and J. G. JONES:** Tidal movements of F-layer semithickness related to atmospheric pressure oscillations (to be presented by W. Dudley Parkinson) (10 minutes)
(3) **C. SALZBERG:** Diffraction patterns in ionospheric reflections (20 minutes)
(4) **JACOB SAVITT:** Recombination and attachment in the F-region during the eclipse of May 20, 1947 (20 minutes)

(5) J. BROWN and J. M. WATTS: Vertical-incidence ionosphere reflections at 50 kc/s (15 minutes)

(6) R. W. KNECHT, V. C. PINEO, and T. N. GAUTIER: Study of meteor ionization by radio pulse echo experiments (20 minutes)

(7) J. FEINSTEIN: Theory and calculations of radio wave reflections from meteor trails (10 minutes)

(8) ELLIOT B. ROBERTS: Current magnetic work of the United States Coast and Geodetic Survey (by title)

Wednesday, May 3, 1950, 09^h00^m, Room 2, (Lecture Room, National Academy of Sciences)

(9) E. O. HULBURT: Survey of the visual brightness of the night sky (10 minutes)

(10) R. TOUSEY, M. J. KOOMEN, and L. DUNKELMAN: A visual photometer for measuring the brightness of the night sky (15 minutes)

(11) C. A. PEARSON and M. J. KOOMEN: Night-sky brightness in Maryland and Greenland during 1949 (15 minutes)

(12) B. W. CURRIE: Night-sky brightness at latitude 52° (15 minutes)

(13) JOHN B. WILCOX: A survey of night-sky brightness at College, Alaska (15 minutes) (to be presented by Harold Cronin)

(14) C. W. GARTLEIN: Aurora Borealis, 1949 (20 minutes)

SECTION OF OCEANOGRAPHY

Tuesday, May 2, 1950, 09^h00^m, Room 3 (Auditorium, General Services Building)

Business Session

Reports of committees and other business

Scientific Sessions

(1) ROBERT S. ARTHUR: Refraction of shallow water waves: The combined effect of currents and underwater topography (10 minutes)

(2) LEON S. POCINKI: The application of conformal transformations to ocean wave-refraction problems (10 minutes)

(3) WILLARD J. PIERSON, JR.: The interpretation of crossed orthogonals in wave-refraction phenomena

(4) ALFRED C. REDFIELD: The limits of tidal resonance in coastal embayments

(5) WALTER H. MUNK: On the wind-driven ocean circulation (20 minutes)

(6) WILLIAM S. von ARX: Some surface measurements of ocean current velocities obtained from a ship under way by means of the geomagnetic electrokinetograph (15 minutes)

(7) E. H. VESTINE: Electric currents in the oceans

(8) B. HAUROWITZ and H. A. PANOFSKY: Stability and meandering of the Gulf Stream (to be presented by H. A. Panofsky)

(9) A. A. THOMPSON: Tidal work on Marguerite Bay, Antarctica (10 minutes)

Wednesday, May 3, 1950, 09^h00^m, Room 1 (Auditorium, National Academy of Sciences)

(10) HOWARD J. PINCUS: Depth-sounding data from coordinated vessels (15 minutes)

(11) DALE F. LEIPPER and HANS KLEIN: Graphs for correction of deep-sea reversing thermometers

(12) W. S. HAMILTON: Forces exerted by waves on a sloping board (20 minutes)

(13) I. I. SCHELL: Further on foreshadowing the severity of the iceberg season south of Newfoundland (15 minutes)

(14) R. W. SCHLOEMER: Surface wind analysis for the Florida hurricane of August, 1949 (15 minutes)

(15) L. O. COLBERT: Oceanographic activities of the U. S. Coast and Geodetic Survey

(16) T. S. AUSTIN: The Navy's oceanographic survey vessels

(17) D. F. LEIPPER: Establishment of the Department of Oceanography in the Agricultural and Mechanical College of Texas

(18) THORNDIKE SAVILLE, JR.: Model study of sand transport along an infinitely long, straight beach (by title)

(19) R. L. WIEGEL and D. A. KIMBERLEY: Southern swell observed at Oceanside, California (by title)

(20) M. P. O'BRIEN and J. R. MORISON: The forces exerted by waves on objects (by title)

(21) J. D. ISAACS and R. L. WIEGEL: The thermopile wave meter (by title)

SECTION OF VOLCANOLOGY

Monday, May 1, 1950, 09^h00^m, Room 2 (Lecture Room, National Academy of Sciences)

Business Session

Reports of committees and other business

Scientific Session

(1) DONALD E. WHITE and W. W. BRANNOCK: The sources of heat and water supply of thermal springs, with particular reference to Steamboat Springs, Nevada, (20 minutes)
(2) GABRIEL DENGO: Eclogitic and glaucophane amphibolites in Venezuela (20 minutes)
(3) V. R. THEOBALD: An hypothesis as to the origin of earthquakes, volcanoes, and intrusive igneous rocks (20 minutes)
(4) P. D. KRYNINE: Cambrian volcanism in eastern North America (10 minutes)
(5) EUGENE CALLAGHAN: Tertiary volcanic sequence and mineralization in the Great Basin (20 minutes)
(6) FELIX CHAYES: Measurement of intercept distances in thin section (10 minutes)

Thermochemistry of natural feldspars

(7) F. C. KRACEK and CHARLES NEUVONEN: Heats of solution of feldspars in hydrofluoric acid (15 minutes)
(8) CHARLES NEUVONEN and F. C. KRACEK: Latent heat of melting of albite and anorthite (15 minutes)

SECTION OF HYDROLOGY

Monday, May 1, 1950, 09^h00^m, Room 3 (Auditorium, General Services Building)

Business Session

(a) Reports of officers
(b) Report of Committee on Honors and Awards
(c) Other business

Scientific Sessions

(R1) F. T. MAVIS: Report of the Research Committee on Dynamics of Streams (10 minutes)
(1) K. J. BERMEL: The hydraulic influence of modifications to the San Dimas Critical-Depth Measuring Flume (by title)
(R2) W. C. LOWDERMILK: Report of the Research Committee on Land Erosion (10 minutes)
(2) GUNNAR M. BRUNE: The dynamic concept of sediment sources (20 minutes)
(3) LEONARD SCHIFF: Surface detention, rate of runoff, land use, and erosion relationships on small watersheds (20 minutes)
(4) E. W. LANE and W. M. BORLAND: Estimating bed load (to be presented by E. W. Lane) (15 minutes)
(R3) ____________________; Report of the Research Committee on Snow (10 minutes)
(R4) L. V. WILCOX: Report of the Research Committee on Chemistry of Natural Waters (10 minutes)
(R5) G. W. MUSGRAVE: Report of the Research Committee on Infiltration (10 minutes)
(5) JOHN B. CAVALLERO, LEMUEL E. MILLER, and DONALD E. WHELAN: Determination of surface runoff by routing infiltrated water through the soil profile (20 minutes)
(R6) H. G. WILM: Report of the Research Committee on Evaporation and Transpiration (10 minutes)
(6) A. RUSSELL CROFT: Evapotranspiration and water available for stream flow (20 minutes)
(R7) C. C. McDONALD: Report of the Research Committee on Runoff (10 minutes)
(7) H. N. HOLTAN and M. H. KIRKPATRICK, JR.: Some broad phases of the hydrology of runoff (to be presented by H. N. Holtan) (20 minutes)
(8) VLADIMIR FROLOW: Morphological significance of the phase of the annual component of river flow in Denmark (by title)

Monday, May 1, 1950, 14^h00^m, Room 1 (Auditorium, National Academy of Sciences)

(R8) MERRILL BERNARD: Report of the Research Committee on Precipitation (10 minutes)
(9) NORVAL L. STOLTENBERG and T. V. WILSON: Interception storage of rainfall by corn plants (to be presented by N. L. Stoltenberg) (20 minutes)
(10) WALTER D. FOSTER: A comparison of nine indices of rainfall intensity (15 minutes)
(11) RAY K. LINSLEY, JR. and MAX A. KOHLER: Rainfall variations over small areas

(to be presented by R. K. Linsley, Jr.) (15 minutes)

(12) FRANK LEWIS: Depth-area-duration curves for design storms (20 minutes)

(R9) S. W. LOHMAN: Report of the Research Committee on Ground Water (10 minutes)

(13) C. K. WENTWORTH: The problem of safe yield in insular Ghyben-Herzberg systems (by title)

(14) RAPHAEL G. KAZMANN: Hydrogeology and water resources (20 minutes)

(15) HOWARD P. HALL: An adaptation of the relaxation method to the problem of seepage toward a gravity well (20 minutes)

(R10) J. L. HOUGH: Report of the Research Committee on Lakes (10 minutes)

(R11) C. E. JACOB: Report of the Research Committee on Permeability (10 minutes)

(16) RONALD C. REEVE and DON KIRKHAM: A comparison of three field methods and the core method for determining soil permeability (by title)

(17) M. S. HANTUSH: Non-steady radial flow in an infinite leaky aquifer (20 minutes)

(18) A. J. K. SHERWANI: Non-steady flow in unconfined aquifers of small thickness with uniform recharge (by title)

(R12) L. A. RICHARDS: Report of the Research Committee on Physics of Soil Moisture (to be presented by W. O. Smith) (10 minutes)

Tuesday, May 2, 1950, $09^{h}00^{m}$, Room 4 (Interdepartmental Auditorium, Conference Room B)

(Jointly with the Section of Meteorology and the American Meteorological Society; see Section of Meteorology, p. 318)

Tuesday, May 2, 1950, $14^{h}00^{m}$, Room 1 (Auditorium, National Academy of Sciences)

(R13) W. O. FIELD: Report of the Research Committee on Glaciers (10 minutes)

(19) M. M. MILLER: The Juneau Ice Field research project (25 minutes)

(20) A. NIZERY: Electrothermic rig for the boring of glaciers (to be presented by P. L. Schereschewsky) (20 minutes)

(21) The remainder of this session will be devoted to a panel discussion on the subject "Hydrology in arid regions," with Merrill Bernard as Moderator. The panel members will be announced later.

SECTION OF TECTONOPHYSICS

Tuesday, May 2, 1950, $09^{h}00^{m}$, Room 2 (Lecture Room, National Academy of Sciences)

Business Session
 Reports of committees and other business
Scientific Sessions

(1) W. M. CADY: Classification of geotectonic elements (25 minutes)

(2) W. S. JARDETZKY: The problem of mountain chains (20 minutes)

(3) W. HAFNER: Stress distribution and faulting (25 minutes)

(4) H. W. FAIRBAIRN: Pressure shadows and relative movement in a shear zone (20 minutes)

(5) J. C. MAXWELL and GABRIEL DENGO: The Carupano area and its relation to the tectonics of northeastern Venezuela (20 minutes)

(6) S. S. WEST: Tectonics of Alaska and adjacent regions (to be presented by Harold Cronin) (20 minutes)

(7) H. E. TATEL: Further considerations of Moon formation through resonance (20 minutes)

Wednesday, May 3, 1950, $09^{h}00^{m}$, Room 3 (Auditorium, General Services Building)
Including papers having a bearing on Seismology

(8) CLIFTON W. LIVINGSTON: An outline of research in subjects related to the mechanics of rock failure (30 minutes)

(9) D. S. HUGHES and H. J. JONES: Variation of the elastic moduli of sedimentary rocks with pressure and temperature (25 minutes)

(10) HATTEN S. YODER, JR.: Change of high-low quartz inversion up to 10,000 bars (15 minutes)

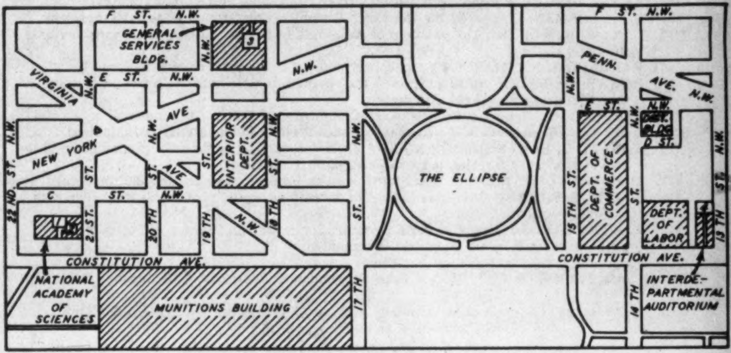
(11) JOHN W. HANDIN and DAVID T. GRIGGS: Predicted fabric changes in artificially deformed marble (to be presented by J. W. Handin) (15 minutes)

(12) FRANCIS J. TURNER and C. S. CH'IH: Observed fabric changes in artificially deformed marble (to be presented by David T. Grigg) (15 minutes)

(13) WILLIAM SCHRIEVER: On the origin of the Carolina bays (15 minutes)

(14) JOHN W. HARRINGTON: The elementary theory of subsurface structural contouring (15 minutes)

Map showing locations of meeting rooms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NATIONAL ACADEMY OF SCIENCES
MUNITIONS BUILDING
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THE ELLIPSE
PENN. AVE. N.W.
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DEPT. OF COMMERCE
DIST. BLDG.
D ST.
DEPT. OF LABOR
4
13 TH ST. N.W.
CONSTITUTION AVE.
14 TH
INTERDE-PARTMENTAL AUDITORIUM

Key to room numbers

1--Auditorium, National Academy of Sciences - National Research Council Building
2--Lecture Room, National Academy of Sciences - National Research Council Building
3--Auditorium, General Services (Old Interior) Building
4--Conference Room B, Interdepartmental Auditorium

NOTES

Room Reservations--Make hotel or room reservations directly with the hotel of your choice as soon as possible (see February issue, p. 155 for word concerning hotels at which block bookings have been made). Bear in mind that advance bookings on which deposits have not been made are cancelled two weeks in advance, and thus, during this interval, chances of making a reservation may be quite good. Our meeting is scheduled for the same week as the convention of the United States Chamber of Commerce. In the last three years, however, we have met at the same time as the convention of the DAR, but at no time, to our knowledge, has it not been possible to find quarters. Even though no advance reservation has been made, it has been possible to arrange for quarters after arrival in Washington through the Greater National Capital Committee (204 Evening Star Building, Washington 4, D. C., Telephone STerling 3535); but they may find it necessary to direct you to a tourist home.

Registration--All members and guests attending any session are requested to complete cards of registration at the Main Registration Desk at the entrance to the Building of the National Research Council - National Academy of Sciences, where Receptionists will be available to supply information regarding meetings, membership, telephone, and mailing facilities, and other local matters. An auxiliary Registration Desk will also be maintained at the entrance to Room 3 (Auditorium, General Services Building). There is no charge for registration.

Discussion--Within the available time, opportunity will be given for discussion from the floor following the oral presentation of a paper. Discussors are urged to prepare their comments for consideration for publication with the paper.

Resolutions--Chairman Earl Ingerson of the Union's Committee on Resolutions, desires to have this Committee fully advised by $15^{h}00^{m}$, Tuesday, May 2, 1950, of any resolutions to be submitted in order that this Committee may have opportunity to prepare them in final form for presentation at the Business Session of the Union on Wednesday afternoon, May 3, 1950. Each resolution presented to the Committee should include (a) names of original submitters, (b) whether presented to a Section, and action taken, and (c) whether action is desired in the Business Session or whether the resolution is to be regarded as being only for a particular Section or as one to be more effective as a general resolution of the whole Union. In addition to the Union Committee on Resolutions, each Section has such a Committee. Section officers can supply information concerning these.

Lounge--The Board Room (behind the Lecture Room) and the Library (opposite the Lecture Room) of the National Academy of Sciences are available for the use of members to meet friends and to hold informal conferences.

Conference Room--The Reading Room (west end of the first floor) of the National Academy of Sciences is available by arrangement for conferences. See J. Putnam Marble, Chairman of the Committee on Meetings, for assignment.

Standard of time--As this program goes to press, there is uncertainty as to whether the District of Columbia will be on Eastern Standard or Eastern Daylight-Saving Time at the time of the meeting. Judging from the past two or three years, however, it is likely that Daylight Saving will be adopted.

ABSTRACTS OF PAPERS

SECTION OF GEODESY

(1) John A. O'Keefe (Army Map Service, Washington, D. C.) The application of tensor analysis to certain problems in geodesy--The notion of equipollence is discussed in its relation to grid azimuth, to convergence, and to the (t-T) correction. The notion of the covariant derivative is applied to the problem of the translation of a coordinate system, and certain corrections are derived.

(2) Floyd W. Hough (Army Map Service, Washington 25, D. C.) International cooperation on a geodetic project--This paper deals with the present status of the least-squares adjustment of the first-order triangulation of Europe. It points out a timely example of international cooperation on a scientific project which has been carried on over the past five years. The project has required a wholehearted contribution of scientific data and a considerable effort in preparation on the part of 12 nations of Western Europe, wherein previous nationalistic isolation has been abandoned in the common interest. The result is a highly successful adjustment now nearing completion in which the most probable positions of more than 3500 primary triangulation stations of Europe will be determined in exact mathematical relationship as to direction and distance, all on a single geodetic datum and on a common figure of the Earth.

(3) Donald A. Rice (U. S. Coast and Geodetic Survey, Washington 25, D. C.) Report on determination of deflections of the vertical from gravity anomalies--A brief resume is given of procedures employed in the Army Map Service - Coast and Geodetic Survey investigation of gravimetric deflections. Criteria for station spacing and accuracy of gravity anomalies are discussed in the light of experience gained in the current project. Results are given for seven astro-geodetic stations in south-central United States, using gravity field radii of from 129 to 179 km.

(4) Lloyal O. Bacon (Michigan College of Mining and Technology, Houghton, Mich.) Gravity surveys of central Pennsylvania--Gravity surveys were made in central Pennsylvania in an attempt to obtain information on subsurface structures near the Allegheny Front. Several significant anomalies were encountered. Interpretation of these anomalies in relation to possible subsurface structures throws some light on the probable causes for the major westward salient in the structure of the Appalachian Mountains of Pennsylvania.

(5) George P. Woollard (University of Wisconsin, Madison, Wisc.) A reconnaissance gravity survey of the Island of Oahu--A network of 30 gravity stations was established in 1948 on the Island of Oahu. Bouguer anomalies show that two large gravity maxima of about 100 mgals each occur which correspond to the centers of two ancient volcanoes, Kaneohoe and Waianae. Strictly on the basis of the geology of the islands it has been shown that the present island of Oahu was formed by the coalescence of two earlier islands formed by these same two volcanoes. Later volcanics from other vents appears to have originated from the earlier primary magma pipes in that there is no pronounced distortion of the gravity field in the vicinity of the crater sources for the late volcanics. In contrast to the isostatic anomalies which show the island to be a gravity high, the Bouguer anomalies show that the island is "low" relative to the surrounding ocean area if allowance is made for the difference in mass of the seawater and granitic crustal material of 2.67 density.

(7) Paul C. Wuenschel (Department of Geology, Columbia University, New York 27, N. Y.) Gravity measurements in South America, 1948, preliminary results--Presentation of gravitational profile across the continent showing Free Air and Simplified Bouguer anomalies. Accuracy of observed gravity and elevation will be discussed. Preliminary interpretation will be given.

(8) Albert J. Hoskinson (U. S. Coast and Geodetic Survey, Washington 25, D. C.) Harmonic analysis of gravity observations--Discussion of harmonic analysis of the fifteen-day series of

gravity observations, Department of Commerce Building, Washington, D. C.

(9) Carl I. Aslakson and Omar O. Fickeissen (U. S. Coast and Geodetic Survey, Washington, D. C.) The effect of meteorological conditions on the measurement of long distances by electronics--In the measurement of long distances by electronic means, meteorological observations serve two functions. (1) The changing index of refraction of the atmosphere with altitude between the ground station and the aircraft bends the ray path changing the length of the path for changing atmospheric conditions, thereby necessitating a varying correction to reduce the measured distance to a geodetic distance. (2) A constant velocity of propagation of electromagnetic waves is assumed in instrument design. The true velocity of the waves varies with changing meteorological conditions and a correction must be applied to change the indicated distance to a true ray distance for variations from the assumed velocity. This paper discusses these two effects and methods currently in use for determining these correction factors.

SECTION OF SEISMOLOGY

(2) H. Benioff, B. Gutenberg, and C. F. Richter (California Institute of Technology) Progress Report, Seismological Laboratory, California Institute of Technology, 1949--Two experimental models of seismometers using capacity transducers are under test. Instruments for use in the study of microseisms are nearing completion. These provide a magnified horizontal projection of the ground motion. Benioff has extended his studies of earthquakes and rock creep. Seismograms of a quarry blast near Corona, California, indicate a wave velocity at a depth of 10 km of 6.5 km/sec, and approximately 8.2 km/sec below the Mohorovičić discontinuity. Reinterpretations of travel time curves for Southern California made independently by Gutenberg and Richter are consistent with this. H. M. Mooney found that the amplitude ratio pP/P is increasingly too large relative to the theoretica expectation as focal depth increases. M. E. Denson found that the epicentral distance of the chief P' focal point is a function of wave period. In P" short period waves carry the greater fraction of energy. K. Ergin has calculated energy partition at the rock-water boundary. He has also studied waves reflected at the core in deep focus earthquakes and finds that in PcP and ScP the horizontal component of ground motion is too large and in ScS and PcS the vertical motion is too large. P. Dehlinger finds that the direction of first motion in S waves of local earthquakes shows correlation with fault displacements. An earthquake on November 17, 1949 apparently originated at a depth of 1700 ft under Terminal Island.

(3) M. A. Tuve and H. E. Tatel (Department of Terrestrial Magnetism, CIW, 5241 Broad Branch Road, N. W., Washington 15, D. C.) Seismic observations, Corona (California) blast, 1949--Seven portable seismic stations were set up to observe the blast of 150,000 lb of high explosive in a quarry operation at Corona, California. The observations were made in conjunction with the permanent station of the California Institute of Technology. The portable stations were strung out in a southeasterly direction up to 325 km. All stations received good records and the arrival times agree with those of the California Institute of Technology. The apparent velocities of the P waves increase from a surface velocity of 5.7 km/sec to a velocity of 6.8 km/sec at a depth of about 10 km.

(4) J. N. Nanda, H. E. Tatel, and M. A. Tuve (Department of Terrestrial Magnetism, CIW, 5241 Broad Branch Road, N. W., Washington 15, D. C.) Prolonged seismic wave reception: Interpretation as scattered waves--If a seismic observation is made close to a shot point and the sensitivity of the receiver is great, it will be observed that the ground remains in unrest for minutes. The source of the energy for this motion has long been a mystery. It is proposed to explain this mystery by the arrival of waves which have been scattered at progressively greater distances. An analysis of this hypothesis with simple assumptions shows that the amplitude of ground motion decreases exponentially with time. To a first approximation, this is what the data show. All attempts to explain this as scattering of surface waves or reflections at discontinuities fail because the decrease then is with some power of the time. This idea of scattering makes it possible to estimate average characteristics of the upper layers of the crust. This is being investigated at present.

(5) Judson Mead (Indiana University, Bloomington, Ind.) Preliminary results of deep crustal reflection studies--The problem of high angle seismic reflections from the deep crustal discontinuities has been argued for many years. A program to explore the possibility of detecting such reflections in the immediate vicinity of large quarry explosions was undertaken in the spring of 1948. The instruments used in this work are described and the preliminary results of the observations of eleven quarry explosions are summarized. Although the existence of deep reflections has not been established, interesting conclusions can be made concerning the amplitude variations and possible sources of the secondary arrivals recorded during the first forty-five seconds following an explosion.

(6) J. Joseph Lynch (Fordham University, New York 58, N. Y.) An investigation of two-second microseisms associated with cold fronts and a new method for tracking the center of the latter--

Two tripartite stations have been set up five air miles apart, each consisting of three two-second horizontal seismographs recording at a drum speed of 600 mm/min. In addition, three stations equipped with two-second vertical and horizontal instruments have been set up on a triangle of five-mile sides recording at a drum speed of 60 mm/min with provision at the main station for switching over to a drum speed of 600 mm/min during a microseismic storm, the better to measure the phase difference between vertical and horizontal components.

(7) Marion H. Gilmore and C. W. Goyder (Navy Hurricane Weather Central, Miami, Fla.) Storm microseisms: A note on their origin, propagation, and measurement--The nature of microseisms is discussed, with particular reference to storm microseisms generated by both tropical and extra-tropical low pressure areas. Certain basic limitations associated with the propagation of microseismic waves between the storm and the recording station are considered. Information is given on the latest techniques for recording storm microseisms and determination of the direction of arrival. Suggested future improvements in methods of instrumentation are discussed.

(8) Andrew A. Thompson (439 E. 71st St., New York, N. Y.) Seismographic work on Palmer Peninsula, Antarctica--A seismographic station was established on Stonington Island at latitude 68° 11′ S, longitude 67° 00′ W over bedrock, 17 ft above sea level in April, 1947. Continuous records were obtained from two sesimographs from May, 1947 to February, 1948, with but a few days omission due to difficulties. The type instruments used were Neumann-Labarre, worked at from one to five seconds natural period, and Sprengnether, horizontal component, worked at 6 1/2 and 22 1/2 sec natural period. The combination was well adapted for local and teleseismic work. Microseismic activity was also easily picked up. A study of microseismic correlation with weather was carried on throughout the year. Weather maps were made from meteorological data from the six British bases in the area, our station on the six thousand foot plateau 17 mi east of the base, our Base at Cape Keeler, and ship reports. The approximate locations of the British Bases are as follows: Laurie Island in the South Orkneys, latitude 60° 45′S, longitude 44° 30′W; Hope Bay at latitude 63° 15′S and longitude 56° 45′W; Deception Island at latitude 62° 58′S, and longitude 60° 35′W; Marguerite Bay at latitude 68° 11′S, longitude 67° 11′W; Port LockRoy in Argentina; and the Falkland Islands.

(11) Pierre M. Honnell (St. Louis University, St. Louis, Mo.) The absolute calibration of a brush accelerometer and its response to square waves of displacement and velocity--It is not too difficult to determine the steady-state sinusoidal response of accelerometers and siesmographs. The absolute calibration of these instruments is a more difficult matter. A new method for the absolute calibration of seismographs and accelerometers dynamically is based upon matching the peak sinusoidal acceleration of the instrument on test against the constant vertical acceleration of gravity. The technique in its present simple form appears to enjoy a precision of better than five parts per 100. The method is described in its application to the calibration of a Brush accelerometer. The response of the same accelerometer to square waves of displacement and velocity, and to simple transient waveforms, is also shown. These results were obtained experimentally with a new electromechanical transducer.

(12) Edward F. Carome (Seismological Observatory, John Carroll University, Cleveland 18, Ohio) An electronic vibration meter--A completely portable electronic instrument which appears to have wide application in the field of vibration measurements has been developed. The circuit is such that a meter responds to the maximum amplitude of a transient or continuous voltage imput. The indication is held for an indefinite time. Used in conjunction with a commercial vibration pick-up, this instrument provides a simple and convenient means of measuring accelerations in structures and of referring them to a standard index of damage.

SECTION OF METEOROLOGY

(1) George S. Benton (Johns Hopkins University, Baltimore, Md.) Meridional transport of water vapor in the atmosphere--The latitudinal distribution of precipitation and evaporation over the Earth are used to determine the net meridional transport of water vapor in the atmosphere. Flux of water vapor is computed as a function of latitude. The importance of water vapor in the meridional exchange of energy between equatorial and polar regions is shown, and the results are explained in terms of the dynamics of the general circulation.

(3) Sigmund Fritz (U. S. Weather Bureau, Washington 25, D. C.) Ozone observations at Washington, D. C.--During 1948 and 1949, ozone observations were made at Washington, D. C. with a Dobson ozone spectrophotometer. The annual cycle of ozone is described. Correlation between ozone and temperatures aloft are discussed together with the variation of the correlation coefficients from month to month. The relation of ozone to surface high and low pressure areas is shown. For lows, the results are rather similar to previous results. For highs, the relationship is less pronounced, and considerably different from other results. Finally, some ozone observations taken

during the occurrence of intense ultraviolet emissions from the Sun are discussed.

(4) C. L. Hosler (Pennsylvania State College, State College, Pa.) Preliminary investigation of condensation nuclei under the electron microscope--Condensation nuclei have been examined and photographed in the electron microscope. The apparatus used and the technique employed to prepare the specimens are described. Photographs of nuclei are included. In the apparatus described, the expansion ratio in the cloud chamber can be controlled, and deposits of nuclei sampled at different expansion ratios can be examined. The image pattern of nuclei consisting of known substances can be established and samples consisting of unknown substances identified.

(6) Duncan C. Blanchard (Pennsylvania State College, State College, Pa.) The behavior of large waterdrops at terminal velocity--An insight into the behavior of large raindrops has been obtained by studying drops of water freely suspended in a vertical air stream. The wind tunnel employed is described. The stroboscopic pictures taken of the waterdrops show that extreme periodic deformations occur on drops more than five mm in diameter. The behavior of drops before and after collision was observed. Drops which come into a region within six cm above another drop usually begin to fall in an ever tightening spiral until collision takes place. The bombardment of large drops with a spray of small droplets showed that complete coalescence never occurred. Many of the smaller droplets would roll across the under surface of the large drop exhibiting a "bounce-off" effect. The breakup of a large waterdrop is easily brought about by imparting a sudden upward acceleration to the air through which it falls. On the other hand, a downward acceleration of the air is relatively uneffective in causing breakup. The influence of the periodic deformation in causing breakup can be demonstrated by actually pumping air into a drop until the air bubble constitutes as much as 30 per cent of the drop. Such "air-bubble" drops show little or no deformation and will thus remain intact even when subjected to extremely turbulent air.

(7) J. Vern Hales (University of Utah, Salt Lake City, Utah) Meridional cross sections of radiational heat losses due to water vapor--Cross sections showing the radiational heat losses due to water vapor radiation have been constructed for summer and winter mean data using the flux divergence chart. These sections extend along about longitude 80° from Salinas, Ecuador, to Arctic Bay, Canada; and from 1000 mb to 400 mb. Significant features of the cross sections are pointed out and discussed, with an attempt being made to interpret the patterns in terms of synoptic features which may have caused them. Cross sections of specific humidity effective in radiation ar shown and discussed briefly. The basic data are those published by Hess in his cross sections of temperature and other factors.

(8) H. H. Larkin, Jr. (189 Van Rensselaer St., Buffalo 10, N. Y.) and B. L. Wiggin (U. S. Weather Bureau, Buffalo 11, N. Y.) Time-lapse motion pictures of the whole sky as an observational tool--An atmospheric wave reaching to the top of the troposphere was observed from the ground and from an aircraft at 20,000 ft. The vertical motions observed from the aircraft, and the cloud evolution as seen from the ground, fulfilled two of the conditions generally believed necessary in the formation of rain; that is, (1) adequate vertical transport, and (2) adequate condensation nuclei. The third condition, an adequate release of water, could not be met because the air involved was too dry. The display suggested a mechanism for the pre-frontal thundersquall. In order to secure a better observation of the phenomena, a camera technique was worked out and applied using time-lapse movies of the whole sky. The equipment and some results of this observational method are shown which indicate that this is a practical and economical tool in the field of nephanalysis.

(9) Arnold Wexler (National Bureau of Standards, Washington, D. C.) Humidity test apparatus, recirculating type--An apparatus which was developed for producing atmospheres of known relative humidity is described. It was designed principally for research and calibration of radiosonde hygron eter elements at temperatures above freezing, but is equally useful at temperatures down to -40° C. It operates by saturating air at one temperature and then raising the air temperature sufficiently to give any desired relative humidity. The air is recirculated continuously in a closed system. Four identical, but independent, recirculating systems are employed. Discrete changes in humidity and temperature are obtained by means of a unique pneumatic valve which permits the hygrometers under test to be switched, easily, from system to system. Checks on the performance of the apparatus by means of the gravimetric method of moisture determination and the psychrometric method show an average agreement in relative humidity of 1.2 per cent as measured and as given by the apparatus.

(11) George S. Benton and Winton Covey (Johns Hopkins University, Baltimore, Md.) Measurement of meteorological variables by use of multiple energy-balance indicators--A method is suggested for computing meteorological variables near the ground, including air temperature, incoming and outgoing radiation, and wind speed. The method involves measuring the temperature of a multiplicity of indicators, each suspended at a given level above the surface of the ground. The temperatures of the indicators are controlled by radiational and convective exchanges of energy between the indicators and their environment. The present status of field tests of the suggested technique is summarized.

(12) J. Sherrod, H. Neuberger, and D. Yerg (Pennsylvania State College, State College, Pa.) New standards for Landsberg's glass-rod method of integrating ultraviolet radiation--Landsberg's method for obtaining integrated values of ultraviolet radiation makes use of small glass rods that, under the influence of ultraviolet radiation, change their color from green to various shades of purple when longitudinally viewed. Investigations of the original standards consisting of a set of pre-exposed and calibrated rods revealed the instability of the glass color. Two new methods of standardization have been developed; one involves a complementary wedge filter by means of which the color of the rod is compensated to neutral, the other one employs a set of partially-exposed rods, so that the rods themselves furnish the chromatic compensation. The stability and saturation characteristics are discussed and tentative calibration curves presented.

(13) William D. Murray, Charles S. Schneider, and James R. Smith (New York University, New York 53, N. Y.) Development and utilization of constant-level balloons--Controls have been developed to keep plastic nonextensible balloons at selected pressure levels in the troposphere and low stratosphere for long periods of time. Instruments have been held at constant level; trajectories have been plotted and the balloons have been used to check dynamic theory. Altitude, load limits, flight duration, and constancy are discussed, and present and future applications are considered.

(14) J. Doyne Sarter, Isadore Katz, and Robert Katz (Naval Research Laboratory, Washington 25, D. C.) A method for the measurement of atmospheric diffusion at intermediate levels using mobile equipment--A description is given of a mobile means of rapidly and repeatedly obtaining data on the areal spread of a puff of smoke from which a parameter characterizing the diffusion in the intermediate layers of the atmosphere can readily be computed. A kiting balloon is used to carry aloft a wired sonde in tandem with a smoke puff generator. Smoke puffs may be emitted and measurements of temperature and humidity taken at any desired height up to the highest level that the kiting balloon is capable of lifting the equipment. Measurements of the areal spreading of smoke puffs have been taken at various heights over water and applied to a theory of atmospheric diffusion developed by O. G. Sutton.

SECTION OF METEOROLOGY

Jointly with Hydrology and the American Meteorological Society

(1) Merrill Bernard (U. S. Weather Bureau, Washington 25, D. C.) Hydrometeorological phases of the water-resources problem--Far-reaching plans for the Nation's major river basins are in the making. Water, playing the leading role, has focused attention on the sources of meteorology and hydrology as the fields in which the water resources of the country will be appraised. Hydrometeorologists will be called upon to reveal areas of water deficiency and abundance, and develop the basis for judging the adequacy of water supplies. They will continue to play an important part in determining flood damage potentiality in the Nation's flood control program.

(2) Theodore W. Kleinsasser (U. S. Weather Bureau, Washington 25, D. C.) Meteorological factors affecting the operation of miltiple-purpose hydrologic structures--Precipitation, temperature, humidity, cloud cover and wind, past, present, and future are the important meteorological elements affecting the operation of hydrologic structures. Effective use can be made of predictions of these elements to achieve greater efficiency in the operation of multiple-purpose hydrologic systems like the TVA system. Special attention is directed to the use of quantitative precipitation forecasts for regulation on the Tennessee River. More reliable quantitative precipitation forecasts and more universal use of these forecasts in the operation of multiple-purpose systems will ultimately affect the design of the structures as well as their operation.

(3) D. B. Krimgold (121 Glenbrook Road, Bethesda, Md.) Erosion and precipitation--The various ways in which precipitation is directly and indirectly related to erosion are discussed. A functional expression is developed for the relationship between amounts of rainfall and snowmelt occurring at rates greater than the rate of movement of water into the soil. An outline is given of the type of information needed to verify the hypothesis expressed by the functional equation and to determine numerical values involved. The fallacy of attempting to arrive at quantitative relationships by statistical methods without formulating hypotheses based on knowledge of the physical factors and forces involved is illustrated by the results of such statistical analysis of rainfall and soil-loss data from the Marlboro, New Jersey Conservation Experiment Station.

(4) Martin A. Mason (Beach Erosion Board, Washington, D. C.) The wind element in beach erosion--Wind is an important factor in the erosion of beaches by reason of direct and indirect effects. Direct effects are usually confined to dry portions of the beach and can be evaluated by the sextant of dune formation. Indirect effects involve the generation of waves and currents which are the principal factors in erosion of shores and beaches. Local winds are shown to be those causing direct effects, while indirect effects may be associated with many wind systems. The use of wind as a constructive agent to combat destructive erosion effects is noted.

(5) Vincent J. Schaefer (General Electric Research Laboratory, Schenectady, N. Y.) The formation of frazil ice and anchor ice in cold water--Evidence is presented to show some of the mechanisms involved in the formation of frazil and anchor ice. It is shown that so-called anchor ice may consist of an accumulation of frazil ice which gathers on underwater objects due to the shape and physical properties of the primary particles. Methods have been developed to study certain aspects of the formation of frazil ice. It is shown that dry ice may be used to greatly facilitate the formation of frazil ice in flowing streams, and the results suggest methods which should be evaluated to determine their feasibility in overcoming certain troubles encountered at hydroelectric installations. Microscope studies are presented to illustrate the structure and physical properties of frazil ice formed in cold water on naturally occurring and artificially produced neclei.

(6) Franklin F. Snyder (Office, Chief of Engineers, Department of the Army, Washington, D. C.) Meteorological factors in hydrologic design--A brief resumé of various hydrologic design problems and the meteorological factors involved in their solution. Some of the special items of interest in determining freeboard requirements in design of Earth levees, dikes, and dams on inland bodies of water to provide for set up and wave action during periods of strong winds will be discussed. Special investigations being conducted by the Corps of Engineers on inland lakes will be described and the results obtained on Lake Okeechobee during the August 1949 hurricane will be reviewed.

(7) Joseph V. B. Wells and Conrad D. Bue (U. S. Geological Survey, Washington 25, D. C.) The water supply in the United States--Development of water shortages in recent years has led to a rather widely accepted belief that stream flow is generally declining. Runoff, which is a residual of precipitation, has reflected in part the downward trends in precipitation during the past two or three decades. However, when we study the few available precipitation records of a century or more in length, which antedate the stream-flow records, it is clear that there are no continuous downward or upward trends. These long-term records strongly suggest that the present phase of diminished precipitation may be temporary. Analysis of stream-flow records show a downward trend in rainfall-runoff relations in some areas, although studies so far fail to indicate a consistent pattern of geographical distribution of those areas. It may be concluded from studies based on available hydrologic records that a decline in surface-water supply on a country-wide basis is not yet significant, and that with certain exceptions the problems that have sprung up as a result of decline in stream flow can largely be met through better utilization practices. In short, our streams continue to be reliable sources of surface water. This paper gives a brief appraisal of surface-water supplies in the United States, with emphasis on the situation in the Northeast.

SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

(1) John W. Graham, O. W. Torreson, and Edgar Bowles (Department of Terrestrial Magnetism CIW, 5241 Broad Branch Road, N. W., Washington 15, D. C.) Magnetic polarizations of Silurian sediments of the eastern United States--Reconnaissance measurements of the polarizations of Tertiary strata of the western United States of ocean cores and of New England varved clays have suggested a constancy of the Earth's magnetic field for the order of 50 million years. Studies in deformed beds have demonstrated that sediments can retain a direction of magnetization for 200 million years. A report will be made of the measurements on 350 samples taken at ten sections of Silurian age. The difficulties of interpreting these data will be outlined.

(2) M. W. Jones and J. G. Jones (Geophysical Institute, University of Alaska, College, Alaska) Tidal movements of F-layer semithickness related to atmospheric pressure oscillations--In accordance with Martyn's theory of atmospheric tides in the F-layer, electron drift velocities are associated with changes in semithickness of the F-layer. Atmospheric pressure patterns are deduced. Pressure variations are correlated with semithickness oscillations.

(3) C. Salzberg (National Bureau of Standards, Washington 25, D. C.) Diffraction patterns in ionospheric reflections--The familiar phenomenon of fading of radio waves received wholly or in part from the ionosphere, is usually explained as a phase interference effect between waves which have traveled different paths. Such waves may include the ground wave, singly or multiply reflected ionospheric waves, or the two magneto-ionic components produced by the Earth's magnetic field. However when a single downcoming wave is isolated by pulse transmission techniques and polarized antenna systems, it is still found to fade at varying speeds. Furthermore this single downcoming wave when received at points separated by about one wavelength gives similar fading patterns which are displaced in time; or fading patterns which are entirely dissimilar, or a combination of both of these in varying proportions. This suggests that the wave arriving from the ionosphere is not specularly reflected, but is composed of a cone of rays diffractively scattered by an irregular ionosphere. When similar fading records displaced in time are obtained these are interpreted to be indicative of an overall horizontal motion of the irregularities, or an

"ionospheric wind." When dissimilar records of fading are obtained these are interpreted to be indicative of a turbulent motion of the irregularities. An attempt is made to determine any consistent diurnal or seasonal tendencies in these phenomena, and to establish whether the effect is produced at the level of reflection or below it.

(4) Jacob Savitt (National Bureau of Standards, Washington 25, D. C.) Recombination and attachment in the F-region during the eclipse of May 20, 1947--The variations of electron density during the solar eclipse of May 20, 1947, for fixed heights in the F-region of the ionosphere are compared with the variations expected under the assumption that the disappearance of electrons is largely through a recombination process or alternatively through an attachment process. The recombination and attachment coefficients vary systematically with height and are consistent with those obtained by other investigators. The best agreement of observation and theory is obtained with the data for 260 km, assuming an attachment process. In addition, it is shown that in describing the eclipse variations account should be taken of possible irregularity in distribution of the intensity of the ionizing radiation over the solar disk.

(5) J. Brown and J. M. Watts (National Bureau of Standards, Washington 25, D. C.) Vertical incidence ionosphere reflections at 50 kc/s--The experimental phase of the low-frequency program of research at CRPL is outlined. Recent results, using pulse techniques, of virtual height measurements in the 50 kc/s region are described. The transmitting and receiving equipment is shown briefly and photographs of the installation at Sterling, Virginia are presented. Typical height versus time recordings are shown with corresponding oscilloscope traces. Evidence of more than one mode of reflection is shown.

(6) R. W. Knecht, V. C. Pineo, and T. N. Gautier (National Bureau of Standards, Washington 25, D. C.) Studies of meteor ionization by radio pulse echo experiments--Experiments at the National Bureau of Standards using radar-type equipment at 27 mc and 40 mc to study the transient ionized trails produced by meteors in the Earth's upper atmosphere are described. Relations between the duration of the sequence of echoes received from a trail, the difference in time between the appearance of a visible trail and the beginning of the echo sequence, the visual magnitude, the angle of incidence of the radio wave at the trail, and the wave frequency are discussed.

(7) J. Feinstein (National Bureau of Standards, Washington 25, D. C.) Theory and calculations of radio wave reflections from meteor trails--Rigorous electromagnetic wave theory is employed to ascertain the magnitude and polarization of the energy reflected from meteor trails of various sizes and electron densities. Two trail models are considered, one possessing a constant value of electron density throughout, and the other, an electron distribution which produces a linear radial variation of effective dielectric constant from unity at the surface of the trail to zero on its axis. It is found that typical observed reflections may be accounted for by trail diameters which are small compared to a wavelength (at about 40 mc/sec), if the incident electric vector lies parallel to the trail axis. Transversely polarized radiation gives rise to very much weaker reflections at such small diameters. The two types become more nearly equal, however, as the trail size is increased.

(9) E. O. Hulburt (Naval Research Laboratory, Washington, D. C.) Survey of the visual brightness of the night sky--The background and scope of a current survey of night-sky light are discussed. Previous studies showed that for latitudes below 45° about one-fifth of the night-sky light was scattered starlight. The survey now in progress extends these studies to higher latitudes.

(10) R. Tousey, M. J. Koomen, and L. Dunkelman (Naval Research Laboratory, Washington, D. C.) A visual photometer for measuring the brightness of the night sky--The instrument described is suitable for night operation in high latitudes. It has no electrical circuits or lamps, and has a lower brightness limit of about $.010\,\mu$L. A phosphor button serves as the comparison source.

(11) C. A. Pearson and M. J. Koomen (Naval Research Laboratory, Washington, D. C.) Night-sky brightness in Maryland and Greenland during 1949--The measurements relate chiefly to the light ascribed to the upper atmosphere, as a function of altitude above the horizon. They do not show any important changes with latitude. Night-to-night and seasonal fluctuations are included in the scope of some of the studies, which are still in progress. Possible correlations with other cosmic data have been examined; the only correlation thus far developed involves seasonal trends of solar coronal indices as observed at Climax, Colorado.

(12) B. W. Currie (University of Saskatchewan, Saskatoon, Canada) Night-sky brightness at latitude 52°--Observations of the night sky brightness at Saskatoon, Canada, latitude 52° 11′ N, indicate that the brightness on clear nights without visible polar aurora is appreciably greater than at lower latitudes. Large differences between the average brightnesses for nights without apparent differences in sky and atmospheric conditions, a seasonal variation in the average brightness

corresponding approximately to the seasonal occurrence of polar aurora, and observations of sky luminosities when polar aurora is present suggest that this increase in brightness is due to light of polar auroral origin.

(13) John B. Wilcox (Geophysical Institute, University of Alaska, College, Alaska) A survey of night-sky brightness at College, Alaska--The results of a series of night-sky brightness determinations, made by means of the NRL Photometer Model 2, No. 3, are given. Data are compiled as mean values of brightness in $m\mu L$ for specific points in the sky over a period of several weeks. Observations were made on clear, moonless nights in both the presence and absence of visible aurorae. A brightness contour map of the compiled data is presented.

(14) C. W. Gartlein (Cornell University, Ithaca, N. Y.) Aurora Borealis, 1949--The National Geographic Society - Cornell University Study of Aurora has continued a full observational program in the last year and a start has been made on analysis of past records. Lines of hydrogen have been observed on several occasions and better measurements have been amde on the H_α line with a grating spectrograph which has a 2″, F/1.6 lens of 50 mm focus. The red nitrogen bands have been resolved to show the triple heads. Considerable evidence of radiation of OI, NI, and NII lines has been obtained. A grating spectrograph using an F/1 lens nine cm focus or an F/2.5 lens of 178 mm focus has been put in operation on the Signal Corps Ionosphere and Aurora Program at Cornell. The photoelectric records contain more examples of the sharp peaks characteristic of certain auroral activity. A catalog of aurora from 1938 to 1946 inclusive has been completed and some analysis made. Tentative results will be given. The publication of this catalog of 2700 items should be discussed to arrive at the format best suited for geophysical use.

SECTION OF OCEANOGRAPHY

(1) Robert S. Arthur (Scripps Institution of Oceanography, La Jolla, Calif.) Refraction of shallow water waves: The combined effect of currents and underwater topography--A solution is given for determining the refraction effect according to Fermat's Principle for the case of shallow water waves moving in any given distribution of current and depth. Application is made to an analytic model of an intense rip current, and the results are compared to actual rips.

(2) Leon S. Pocinski (New York Univesity, New York 53, N. Y.) The application of conformal transformations to ocean wave-refraction problems--If the bottom contours are considered straight and parallel, and if the usual assumptions are made, a simple differential equation for the orthogonals can be derived from Snell's Law. Solutions to the equations are easily obtained. Conformal transformations may be applied to change the contours in the complex Z plane into several different configurations in a complex W plane. In each case an orthogonal in the Z plane maps into a new orthogonal in the W plane and thus a solution to the problem of wave refraction over the contour configuration in the W plane is obtained. The expression for K_d is then derived from the orthogonal pattern. Cases treated include a circular island, a reef and a bay with parabolic contours, and twin islands. The method indicates considerable future possibilities in different applications.

(4) Alfred C. Redfield (Woods Hole Oceanographic Institution, Woods Hole, Mass.) The limits of tidal resonance in coastal embayments--The amplification in the range of tide at the head of an embayment relative to the outer sea is attributable to resonant phenomena in the sense that it depends upon relations between the wave period and the dimensions of the channel. Theoretical treatment of the tides as standing waves modified by damping of the primary and reflected progressive waves, into which standing waves may be resolved, permits an estimate of the amplification as a function of the damping coefficient and the phase change undergone by the primary wave along the length of the channel. A method will be described which enables the damping coefficient and the phase relations of the primary wave to be determined from data for tidal range and time of high water along a channel. With such damping coefficients as are found to apply to typical coastal bays, it appears that the augmentation of the tidal range will not be greater than fourfold. In the Bay of Fundy, the conditions for resonance are not ususual. The exceptional range in tide is attributable to the great range in tide in the Gulf of Maine combined with optional conditions for amplification in the Bay itself.

(5) Walter H. Munk (Scripps Institution of Oceanography, La Jolla, Calif.) On the wind-driven ocean circulation--The ocean circulation induced by zonal winds has been derived for a triangular ocean basin. The method, which involves the "boundary layer" technique, can be extended to a more general wind system, and to ocean basins of arbitrary shape provided the boundaries are not too irregular. In low and mid-latitudes the principal effect of an inclination, θ, of the western boundary relative to a north-south direction is to widen the western current (Gulf Stream) by the factor $(\sec\theta)^{1/3}$ and to reduce the current intensity by a similar factor. The variation in the circulation pattern associated with a variation in the value of the lateral eddy viscosity is noted.

(6) William S. von Arx (Woods Hole Oceanographic Institution, Woods Hole, Mass.) Some surface measurements of ocean-current velocities obtained from a ship under way by means of the geomagnetic electrokinetograph--A brief description of the basic principles of the electromagnetic method of observation, and of the geomagnetic electrokinetograph, an instrument applying the electromagnetic method which permits the measurement of ocean-current velocities from a ship under way. The results of some surveys of the surface circulation in areas near the Grand Banks of Newfoundland, and along the line joining Montauk Point, Long Island, and Bermuda. Discussion of a comparison of electromagnetic observations of velocity with those obtained simultaneously by the method of dynamic sections.

(7) E. H. Vestine (Department of Terrestrial Magnetism, CIW, 5241 Broad Branch Road, N. W., Washington 15, D. C.) Electric currents in the oceans--The electric currents induced within the oceans by fluctuations of the geomagnetic field and by moving ocean water are estimated. Some tentative electric current patterns associated with estimated mass-transport systems of the oceans are roughly indicated. Other sources of electromotive forces in the ocean are briefly noted. The possibility of using electrical methods effectively for estimating mass transport of ocean water is discussed.

(8) B. Haurwitz and H. A. Panofsky (Woods Hole Oceanographic Institution, Woods Hole, Mass. and New York University, New York 53, N. Y.) Stability and meandering of the Gulf Stream--It is suggested that the meandering of the Gulf Stream can be produced by the instability of the velocity profile across the current. Various theoretical models are considered which resemble the Gulf Stream inasmuch as they have a sharp shear zone on the left side (facing in the direction of the Gulf Stream) where the current increases vary rapidly to its maximum velocity and a much broader transition zone where the velocity decreases again. It is found that instability exists under certain conditions when the shear zone is not too close to the continental shelf. The type of observations required for a check of this hypothesis is discussed.

(9) Andrew A. Thompson (439 E. 71st St., New York, N. Y.) Tidal work on Marguerite Bay, Antarctica--In April 1947, a tidal house was erected on stagnant ice where an ice toe met the dead part of a glacier in latitude 68° 11′ S, longitude 67° 00′ W on Stonington Island in Marguerite Bay, Palmer Land, Antarctica. Continuous recorded tidal records were obtained from April, 1947 through February, 1948, on a Standard Automatic Tide Machine used by the Coast and Geodetic Survey. Periods adding up to a bit over a month are missing due to destruction of site by sea ice, freezing conditions, and other difficulties. In elevation, the records were tied into at least three markers on bed rock.

(10) Howard J. Pincus (Ohio State University, Columbus, Ohio) Depth-sounding data from coordinated vessels--In the summer of 1949, depth-sounding data were collected by four coordinated U. S. naval vessels crossing the North Atlantic. The sounding data are continuous, except for periods of storm and equipment failure. Data are continuous across the Mid-Atlantic Ridge. The positions of the ships, with respect to each other and to geographical coordinates, are derived from the independent navigation data of each vessel and from the flagship's radar control. Preliminary comments are made on the bottom topography, as defined by this method.

(11) Dale F. Leipper and Hans Klein (A. and M. College of Texas, College Station, Texas) Graphs for correction of deep-sea reversing thermometers--The readings of deep-sea reversing thermometers must be corrected for the changes due to differences between the temperature at reversal and the temperature at which the thermometer is read, and for calibration errors. In handling large amounts of deep-sea temperature data obtained by use of such thermometers, it is convenient to prepare an aid in computation which is especially designed for each particular thermometer. A master graph is described from which it is possible in a few minutes time to reproduce and label a computation aid for a given protected thermometer, once the volume of its mercury bulb and its calibration data are known. In addition to ease of preparation, the aids described have the further advantages of permitting more rapid and more accurate computation and of being less fatiguing in use than other methods. A computation aid which may rapidly be constructed for a particular unprotected reversing thermometer and which is efficient to use is also described.

(12) W. S. Hamilton (Northwestern Technological Institute, Northwestern University, Evanston, Ill.) Forces exerted by waves on a sloping board--To determine the effectiveness of partially submerged boards having a slope of about one on five in reducing wave heights and the forces the structure would have to resist, a piece of phywood was mounted on force-measuring cells in a towing tank and subjected to waves of various size and steepness. The cells were short, watertight, tubular columns with SR4 strain gages mounted inside. The irregular, oscillating strains caused by the wave action were recorded on a moving tape by a two-channel oscillograph. Data are presented in graphical form to show the relation between the length and height of waves, inclined length of slope, and other variables and the force components and wave heights behind the board. The measured

forces are compared with estimated values obtainable from principles of mechanics when simplifying assumptions are made. It was found that the forces were of reasonable magntiude and that the stilling action decreased as the wave length was increased. A short sixteen millimeter movie will be shown.

(13) L. I. Schell (Woods Hole Oceanograpnic Institution, Woods Hole, Mass.) Further on foreshadowing the severity of the iceberg season south of Newfoundland--An examination of the North Atlantic weather elements previously considered by Smith and Groissmayr to influence the severity of the iceberg season south of Newfoundland indicated that steeper than normal pressure gradients, for example, between Norway and Iceland, which may be taken to measure greater inflows of air into the Arctic and which in the past papear to have been followed by greater outflows over the general Greenland and Baffin land area and a greater egress of bergs to Newfoundland waters, have ceased in recent years to be followed on the whole by above normal berg counts off Newfoundland, probably because of the marked change in the circulation in northeastern North Atlantic. On the other hand, steeper Labrador to South Greenland pressure gradients during December to March, which suggest stronger northerly winds along the Labrador Coast, continue as before to indicate on the whole above normal berg counts off Newfoundland the following season. Also, the December-March temperatures at Newfoundland, Bermuda, and Scandinavia, which are a measure of the intensity of the general circulation in the North Atlantic and adjacent areas, when taken together show a marked connection with the following ice severity off Newfoundland. A formula embodying the December-March Belle Isle to Ivigtut pressure fall and temperatures at St. John's, Bermuda, and Upsala was derived using, as before, data to 1926 inclusive. Employing the 23-year period 1927-1949 as a test, the correlation between the computed and actual deviations from the long-term average (1880-1926) is $r = 0.69$. Also, of the 11 cases out of the 23 when the pattern indicating either a below or above normal iceberg count was marked (computed departure ± 1.0 on scale of 10), ten agreed as to sign with the actual deviation in the iceberg severity. The on the whole favorable performance of the formula during the past 23 years suggests its possible application in actual foreshadowing.

(15) L. O. Colbert (U. S. Coast and Geodetic Survey, Washington 25, D. C.) Oceanographic activities of the U. S. Coast and Geodetic Survey--As part of its work of surveying and charting the coastal waters of the United States and possessions, the Coast and Geodetic Survey is accumulating oceanographic and geophysical data pertaining to depths of water, character of sea bottom, physical properties of sea water, and tides and currents. Hydrographic surveys were made during the year along portions of the Atlantic, Gulf, and Pacific coasts. In Alaska surveys were continued in the Aleutian Islands, in Bristol Bay, and on other areas of Alaska including the Arctic coast. A new seamount was discovered in the North Pacific Ocean, about 800 mi northwest of Seattle, rising to a depth of 665 fm from surrounding depths of 2100 fm. Further improvements were made in the Electronic Position Indicator equipment which will insure greater accuracy in offshore hydrographic surveys. The expanded tide and current program was continued. Work in this country was supplemented by participation by the Bureau in special tidal projects in other countries. A communication plan for the seismic sea wave warning system for the Pacific was put in operation.

(18) Thorndike Saville, Jr. (University of California, Berkeley 4, Calif.) Model study of sand transport along an infinitely long, straight beach--The purpose of this investigation was to study the rate of littoral transport induced by wave action on a straight beach inclined to the direction of the wave crest, and to relate the change and magntiude of this rate to the wave characteristics. Waves were generated in a wave tank and allowed to move onto a model beach. The incident waves made an angle with the beach, with the result that a littoral movement of sand was established along the beach. The relationship between the steady state rate of transport and the wave characteristics was investigated.

(19) R. L. Wiegel and H. L. Kimberley (University of California, Berkeley 4, Calif.) Southern swell observed at Oceanside, California--A wave recorder was in operation at Camp Pendleton, Oceanside, California from May 4 through September 1949. Because of its fortunate location in relation to the Western Hemisphere's hydrography, it recorded southerly swell almost continuously throughout the summer, the origins of which appear to lie in the area between latitude 40° and 65° S, and longitude 120° and 160° W. Swell from the south through southwest was found to run almost continuously from May through September, and to dominate the surf zone for that period. Twenty- to thirty-minute averages (taken three times daily) of the "significant" breaker heights ranged from two to six feet, with most breakers being between two and four feet. The "maximum" breakers occurring during the twenty- to thirty-minute periods were usually between four and eight feet with heights of ten to twelve feet observed on occasions. The average wave period of the Southern Swell ranged from twelve to eighteen seconds with short-time averages of predominant groups as twenty-two seconds.

(20) M. P. O'Brien and J. R. Morison (University of California, Berkeley, Calif.) The forces

exerted by waves on objects--Experiments on the forces exerted by oscillatory waves on cylindrical piles have shown that the acceleration forces are of the same order of magnitude as the drag forces associated with the orbital velocities. The movement of sand and gravel on the ocean floor has not been accounted for satisfactorily in terms of the orbital velocities at the bottom and it appears likely that accelerative forces inherent in the oscillatory motion play an important part in this problem of geomorphology. A second factor may also be involved, namely the flow into and out of the permeable bed and the related vertical pressure gradient immediately at the bottom. This report deals with an idealized situation, namely the forces exerted on a single sphere in contact with the bottom.

(21) J. D. Isaacs and R. L. Wiegel (University of California, Berkeley, Calif.) The thermopile wave meter--The thermopile wave meter is designed to be a low cost, simple yet durable instrument which can be considered expendable upon its installation in the ocean. Its electrical characteristics are such that the cable requirements are not rigorous. Its construction is simple. A synthetic rubber bellows is mounted on a plastic base which is in turn mounted on a brass cable connection. A thermopile is mounted inside the bellows with one group of junctions in contact with the air chamber of the bellows, and the reference junctions, insulated from the air chamber, in thermal cantact with the surrounding sea water. Thus when a wave passes over the unit, the crest and trough produce a compression and expansion of the bellows with the corresponding temperature change in the gas due to the polytropic cycle. The temperature difference between the air chamber and the sea water causes an emf from the thermopile, which is transmitted to shore by means of a two conductor submarine cable, and recorded on a commercial null recorder.

SECTION OF VOLCANOLOGY

(1) Donald E. White and W. W. Brannock (U. S. Geological Survey, Washington 25, D. C.) The sources of heat and water supply of thermal springs, with particular reference to Steamboat Springs, Nevada--Thermal springs are classified as (a) non-volcanic; heat and water supply are not immediately related to volcanism; (b) intermediate; excess heat is due to abnormally high geothermal gradients resulting from volcanism, but the water is entirely meteoric; and (c) volcanic; excess heat, much of the mineral content, and part of the water are from a volcanic source. Lines of evidence indicating the origin of a thermal spring system are (1) temperature relations, including surface temperatures of springs, geothermal gradients and heat inventory of the spring system, and possible sources of excess heat; (2) mineral content of the thermal water and its possible sources, with attention focused on the more soluble components that are seldom deposited in veins (Chlorine, boron, and to a lesser extent sulphur and carbon dioxide in their various chemical combinations are critical indicators, particularly when considered together.); (3) composition of a associated gases; (4) variations in spring discharges and water levels, as related to variations in meteoric water supply; (5) isotopic composition of spring and meteoric waters; and (6) regional and local geology, and in particular the age and extent of any volcanic rocks. These lines of evidence, when applied to Steamboat Springs and evaluated, definitely indicate a volcanic origin. The three-dimensional picture of the Steamboat Springs system is described. Meteoric water migrates downward and toward the core of the system, with stratigraphic and structural control, and mixes with rising volcanic water. This migration is due to differences in density related largely to temperature; artesian conditions are not essential.

(2) Gabriel Dengo (Princeton University, Princeton, N. J.) Eclogitic and glaucophane amphibolites in Venezuela--Several occurrences of amphibolites with sodic pyroxenes and amphiboles are found in association with garnet amphibolites within the metamorphosed sedimentary rocks of northern Venezuela. They are interpreted as having been originally shallow basic intrusive rocks and perhaps tuffaceous sediments. Some of these rocks have affinities with eclogites, and are interpreted as being a kind of metastable mineral assemblages formed under the physical conditions of medium grade dynamothermal regional metamorphism. The interpretation of the origin of eclogites from elsewhere as a high temperature and high pressure facies does not hold true for the rocks in question. Glaucophane schists seem to have a similar origin though perhaps formed under a lower grade of metamorphism. The conditions that are conducive to the formation of these metastable assemblages are not known. There is a possibility that they may be due to a particular bulk composition, to the action of permeating solutions during metamorphism, or to the catalytic action of shearing stress.

(3) V. R. Theobald (Emmanual College, Saskatoon, Sask., Canada) An hypothesis as to the origin of earthquakes, volcanoes, and intrusive igneous rocks--The similarity of the astronomical bodies suggests the possibility of finding in the Earth a process corresponding to the production of sunspots in the Sun. On the basis of this analogy it is proposed that vortexes are produced in the Earth's interior which rise and are dissipated in the crustal layers. Earthquakes are considered to arise when the radial pressure, due to the rotation of the vortical material, is able to rupture the surrounding rocks. The intrusion of the fluid vortical material into these crevices and along

other lines of weakness in the crust will give rise to a wide range of intrusive igneous rocks. Volcanoes are considered to occur when natural vents, such as faults and the conduits of former volcanoes, permit the extrusion of the vortical material at the surface. An attempt is made to explain all the more general features of earthquakes, volcanoes, and intrusive igneous rocks on the basis of this process, and to make plausible the production of these vortexes in the Earth's interior.

SECTION OF HYDROLOGY

(1) K. J. Bermel (University of California, Berkeley, Calif.) The hydraulic influence of modifications to the San Dimas Critical-Depth Measuring Flume--An experimental determination of various factors which affect the rating of critical-depth measuring flumes is presented in this paper. Those factors investigated included entrance conditions, floor slope, wall and floor friction, length of flume, method of measuring the head, and the effect of an idealized obstruction in the entrance channel.

(2) Gunnar M. Brune (Soil Conservation Service, Milwaukee 3, Wisc.) The dynamic concept of sediment sources--Using 200 upland sample areas and 23 valley cross-sections, a study was made of rates of sediment production and sediment sources from the headwaters of the Sangamon River of Illinois to its mouth. It was found that as the size of drainage area increases, the upland sources of sediment, such as sheet and gully erosion, become less important, while the bottomland sources, such as streambank erosion, flood-plain scour, and valley trenching, become constantly more important. The writer maintains that this dynamic concept of changing sediment sources with changing size of drainage area applies not only to the Sangamon River watershed, but to any watershed. It was also found that the annual rate of sediment production in the Sangamon watershed decreases from an average of 2,940 tons/sq mi of drainage area in the headwaters to 746 tons/sq mi at the mouth. This agrees with previous studies by the writer, which show that generally rates of sediment production decrease with increasing size of drainage area, for reasons which are set forth in the text. The dynamic concept of sediment sources is compared with the previously widely used static concept based upon "total erosion" figures in a watershed, and the errors involved in the older concept exposed. One of the more important conclusions drawn from this study is that streambank and other forms of bottomland erosion have not been given enough attention by the various agnecies concerned with their control, in comparison with their importance when viewed in the light of the dynamic concept.

(3) Leonard Schiff (Soil Conservation Service, Coshocton, Ohio) Surface detention, rate of runoff, land use, and erosion relationships on small watersheds--Infiltration curves were derived for small watersheds in different land use without using relationships of rate of surface-runoff q and surface-detention D relationships. Relationships between q and D were then determined for both the rising and falling sides of hydrographs and were represented by equations having the form $q = KD^m$. Appreciable differences in m were found between the rising and falling sides of each hydrograph. These differences are contrary to former assumptions which were based largely on plot data. Theoretically and experimentally, it has been shown that m is 3 for laminar flow. Experimental evidence indicates that m is approximately 1.67 for turbulent flow. Values of m, particularly for the rising side of hydrographs, were found to increase as the height and density of crop increased. Such values are more nearly in the laminar range. However, for an individual storm, m represents average values over the watershed area and certain portions of the flow occur in rivulets where velocities and depths are greater than the average. This results in a higher Reynolds Number in the range of turbulent flow. Values of m on the falling side of the hydrograph were always in the turbulent range, except for a few values in the transition range between laminar and turbulent flow. Average velocities of water flow as surface detention were determined based on the rates of flow, depth of surface detention, and the area and shape of watersheds. Relationships between velocities so determined and actually measured on plots are indicated. Velocities increased with slope and were highest under corn coincident with the greatest erosion. For reasonably similar velocities in wheat and corn areas, erosion was less under the former indicating the greater binding power of more numerous roots. Erosion was also rather low under meadow. Such cover generally plays an important part in reducing the impact of raindrops, in binding and holding soil, and in reducing the velocity of surface detention.

(4) E. W. Lane and W. M. Borland (U. S. Bureau of Reclamation, Denver, Colo.) Estimating bed load--The measurement of the sediment load of streams usually consists of securing samples of the material carried in suspension a greater or less distance above the stream bed. For many purposes it is highly desirable to know the magnitude of the total sediment load carried by a stream, but in most cases it is practically impossible to measure it. Ordinarily the total load is approximated by estimating the magnitude of the load not indicated by the suspended load samples. The

ratio of this unmeasured load to the measured suspended load varies greatly, depending on a number of conditions. Although measurements of total load are extremely rare, by keeping certain principles in mind, it is possible to reduce considerably the uncertainty of the ratio of the unmeasured to the measured load, and therefore decrease considerably the probable error in estimations of total load. The purpose of this paper is to set forth these principles.

(5) John B. Cavallero, Lemuel E. Miller, and Donald E. Whelan (U. S. Forest Service, Upper Darby, Pa.) Determination of surface runoff by routing infiltrated water through the soil profile--The amount of infiltrated water is determined by routing available supply through the soil profile for successive periods of uniform intensity rainfall. The routing procedure employs percolation rates, transmission rates, and retention and detention storage values determined by extensive field tests for each horizon within the profile. Surface-detention storage and recovery of infiltration capacity are thereby accounted for during periods of light or no rainfall. Surface runoff occurs when rainfall intensity exceeds the infiltration rate regardless of all other conditions. However, it also occurs when rainfall intensity exceeds the percolation rate at any point in the soil horizon provided that the soil above such point has become saturated.

(6) A. Russell Croft (U. S. Forest Service, Ogden, Utah) Evapotranspiration and water available for stream flow--The effect of water utilization by aspen trees, herbaceous plants, and bare ground on water available for stream flow was studied for three summers on the high and humid Wasatch Mountains of Utah. Total evapotranspiration during the June 1-September 15 growing season averaged about 18, 15, and 11 inches of water for the aspen, herbaceous, and bare sites, respectively. These amounts represent the evapotranspiration deficit in six-foot deep soil mantles (the difference between moisture content at field capacity and that at the end of the growing season), plus summer rainfall, minus interception losses and surface runoff. Aspen used an estimated additional one inch of water in flower and early leaf development during the spring snowmelt period prior to June 1. Evapotranspiration deficits averaged about 12, 8, and 4 inches of water for aspen, herbaceous, and bare sites, respectively. These deficit differences reflect penetration of roots and withdrawal of water throughout the six-foot mantle under aspen and to a depth of only four feet under herbaceous cover; and the absence of roots in the bare type. Evapotranspiration deficit represents the amount of water that must be replaced before water can pass through the soil to streams or ground water. Accordingly, from a normal spring snow pack containing 30 inches of water, and without correction for any evaporation losses from snow, there would be available for stream flow about 17, 22, and 26 inches of water from the aspen, herbaceous, and bare sites respectively. In a year when water in the snow pack is only 50 per cent normal, or about 15 inches, water available for stream flow would be only 12, 32, and 42 per cent of normal from aspen, herbaceous, and bare types. Summer rains which averaged about 7.0 inches, produced 0.01 and 0.02 inches of overland runoff from the aspen and herbaceous sites, respectively. No soil was eroded from these areas. On the bare areas, however, rainstorm runoff averaged 0.40 inches and this runoff carried away the equivalent of about eight tons of soil per acre. Removal of aspen, and probably other deep-rooted species, may be a means of increasing water yield provided this can be accomplished without increasing rainstorm runoff and soil loss.

(7) H. N. Holtan and M. H. Kirkpatrick, Jr. (Soil Conservation Service, Blacksburg, Va.) Some broad phases of the hydrology of runoff--This study portrays three broad phases of hydrology, (rainfall, infiltration, and hydraulics of flow) as they affect the occurrence of surface runoff from rainfall. It is reported in two parts in order to depict two concepts of application. Part I develops and applies these phenomena as they occur on watersheds of a single cultural practice unit. Part II extends the application to watersheds containing several different cultural practice units.

(8) V. Frolow (Vice President, International Association of Hydrology, IUGG, 63 Rue Claude Bernard, Paris, France) Morphological significance of the phase of the annual component of river flow in Denmark--The annual component of river flow in Denmark has been calculated by the method of linear combinations of ordinates [see Terr. Mag. and Elect., 1936, pp. 15-28], forming the multiple combination: S_1, S_2, Z_2, Z_3, $(s_1)_{12/2}$, $(s_2)_{12/2}$. The phase distribution of this component is the one related to July, 1941. The phase is expressed in hundredths of the annual period. It can be seen that the streams in Denmark are almost at the lowest level in July and that some of them have then already reached this stage. A map shows that a geographical decrease of the phase towards the north certainly exists. This is demonstrated by two stations 200 km apart situated in comparable conditions of relief, which show a difference of four per cent (about 15 days). The phase diminution is of the order of one day per 15 km, in accordance with the value found for the Tobol basin. But the main feature of the phase distribution in Jutland is the relation with the relief of the country. The hills of this peninsula, although of low altitude (max. 172 m), are sufficient to determine in the evolution of the annual component of flow, differences which may be of the order of a month. The slopes of Jutland descending towards the west provoke an earlier flow compared with the eastern slopes. It is evident that only small differences are caused by unequal flow velocities and by the differences of river length, which are small in Denmark. Relative to a regular

distribution of the phase (uniform diminution towards the north) the advance due to relief varies from 26 to 18 days per 100 m altitude The map shows how the flux coming from the North Sea strikes the hills of Denmark which deflect them round by the north and south, forming a perturbed state advancing the phase on the western slope and retarding the phase on the eastern slope. Although the relief of the Danish island is low, it is sensitive in the phase distribution of the annual component of flow. This is particulary clear for the isle of Sjaelland and the little data in hand for Falster and Lolland.

(9) N. L. Stoltenberg and T. V. Wilson (Soil Conservation Service, Lafayette, Ind.) Interception storage of rainfall by corn plants--The processes resulting in interception and interception storage of rainfall by corn plants are discussed and terms defined. Values for two components of interception storage on mature corn plants have been determined under several conditions. The dominant factor affecting the value for residual interception storage on mature corn is the plant population. The amount and rate of rainfall have little effect on residual storage after sufficient rain has fallen to fill the storage pockets. Maximum residual interception storage on mature corn was found to be about 0.02 inch for a corn plant population of 15,000 plants per acre.

(10) Walter D. Foster (University of North Carolina, Raleigh, N. C.) A comparison of nine indices of rainfall intensity--To supplement four frequently used simple measures of rainfall intensity, namely, five-minute intensity, 15-minute intensity, 30-minute intensity and average intensity (P/t), five compounded indices have been suggested. Through the use of appropriate statistical methods, these nine measures are compared for their relative merit in characterizing rainfall intensity.

(11) Ray K. Linsley, Jr. and Max A. Kohler (U. S. Weather Bureau, Washington 25, D. C.) Rainfall variations over small areas--Variations in rainfall over small areas have been a subject of considerable interest to hydrologists and meteorologists, but, because of inadequate data, little analytical work has been possible. The precipitation gage network established for the Army-Navy-NACA-Weather Bureau Thunderstorm and Cloud Physics Projects near Wilmington, Ohio, included 55 rain gages at approximately two-mile intervals. Utilizing data from this network the authors have analyzed the variations in average precipitation for storms computed from networks of differing densities and the relation between point and areal average values of rainfall in storms.

(12) Frank Lewis (U. S. Bureau of Reclamation, Denver, Colo.) Depth-area-duration curves for design storms--The mathematical characteristics of depth-area-duration curves for observed storms and for design storms are discussed and compared with those of other graphical presentations. The use of the curves for determining the critical areal extent of design storms is discussed and illustrated. The identification of areas receiving excess precipitation is shown to be important in the determination of design storms.

(14) Raphael G. Kazmann (Ranney Method Water Supplies, Columbus, Ohio) Hydrogeology and water resources--The concept of "safe yield" as applied to aquifers composed of granular materials is analyzed. The inherent difficulty in applying this concept to the practical problems of developing ground-water supplies and controlling ground-water development is pointed out. A possible solution to these difficult problems is proposed. This solution is based on classifying aquifers with respect to function and relating the withdrawals of water from aquifers to the total water resources of the area.

(15) Howard P. Hall (Northwestern University, Evanston, Ill.) An adaptation of the relaxation method to the problem of seepage toward a gravity well--In a thesis recently submitted to the Faculty of Engineering at Harvard University, S. T. Yang has developed a modification of Southwell's relaxation method as applied to the problem of axially symmetrical three-dimensional flow of an incompressible fluid having an initially unknown boundary. The details of this modification are presented briefly, and its advantages are illustrated by its application to the determination of the flow pattern corresponding to the seepage of water through sand toward a gravity well. The specific problem upon which the discussion is based is the theoretical analysis of flow in a relatively large-scale model used by the writer for an investigation of seepage toward a well.

(16) Ronald C. Reeve and Don Kirkham (Iowa State College, Ames, Iowa) A comparison of three field methods and the core method for determining soil permeability--Three field methods - piezometer method, auger hole, and tube method - and the conventional undisturbed core method for measuring soil permeability are compared at several locations. Natural channels in the soil, such as cracks and root and worm holes, cause extreme variations in results by the undisturbed core method and cause the rate of rise, in small diameter piezometers, to deviate from the theoretical. This deviation becomes negligible as the pipe diameter is increased. Size of sample associated with each method causes differences in measured values in non-uniform soils. In anisotropic soils the piezometer and auger hole methods measure essentially the horizontal permeability; whereas

the tube and undisturbed core methods measure the vertical. The piezometer method, using one-inch diameter pipes, appears to be the most convenient and best for general use where there are few natural channels in the soil. In soils containing many natural channels the effect of such channels in causing erroneous readings is negligible if either a large size piezometer or the auger hole method is used.

(20) A. Nizery (Chief Engineer of Bridges and Highways, Hydraulic Research and Investigations, 20 Rue Hamelin, Paris 16, France) Electrothermic rig for the boring of glaciers--After a brief history of the boring of a glacier, the theoretical boring speed of a thermic drill acting by melting of the ice is studied and the optimum characteristics of a drilling bit body including electric heating resistance discussed. The electrothermic boring rig developed by the Hydraulic Research Service of Electricité de France is then described and the results of the first boring program in 1948 and 1949 on the glacier "Mer de Glace" near Chamonix presented. The average drilling speed of the bit was 20 to 25 m/hr for an average diameter of the drilling between 60 and 80 mm. The deepest boring was stopped by the bed-rock 195 m below the surface of the glacier.

SECTION OF TECTONOPHYSICS

(1) Wallace M. Cady (U. S. Geological Survey, Washington 25, D. C.) Classification of geotectonic elements--The major elements of the Earth's surface, particularly the continental blocks, geosynclines, oceanic basins, and related features, are geotectonic elements. These elements form the framework within which the various magmas, sediments, and ore minerals develop. The ever increasing attempts to provide definitive genetic descriptions of rocks and ore minerals and their relationships in space and time have made necessary an overall and integrated classification of the tectonic elements. The basis for a genetic classification of geotectonic elements is provided by the works of Bubnoff, Stille, Kay, Umbgrove, and Kuenen. A significant feature of the classification is an evolutionary development of geotectonic elements through four critical stages proposed by Stille. Characteristic geotectonic elements that were formed in each of these stages are described and their genetic relationship to elements formed in preceding and succeeding stages are indicated. The tectonic situation during each stage is illustrated with profile cross sections of a typical continent to clarify interrelations emphasizing the various types of geosynclines. The geotectonic elements are illustrated with examples, and characteristic magnatic and sedimentational features are briefly indicated. The terminology in current use to designate the various geotectonic elements will be introduced at the close of the discussion.

(2) W. S. Jardetzky (209 W. 97th St., New York 25, N. Y.) The problem of mountain chains--In order to explain the formation of ranges of mountains on the Earth's surface, the solution of three following fundamental problems must be given: (1) the mechanism of the folding of a mountain range, (2) the field of forces corresponding to an actual simultaneous distribution of mountain ranges, and (3) the changes of this field during the geological history. Four principal types of the mechanism of folding may be discerned. The hypothesis of the zonal rotation of the Earth leads to the distribution of forces in the crust which can produce the mountain building in the Tertiary. A certain variation of this field of forces in the preceding geological periods may be established.

(3) W. Hafner (Shell Oil Co., Houston 1, Texas) Stress distributions and faulting--Tectonic deformations in the Earth's crust result from a condition of interval stress which, in turn, is caused by primary and secondary forces. In the geological literature we find a great deal of discussion based on a direct connection between forces and deformation, completely by-passing the concept of stress. This often leads to confusion, rather than elucidation, of the causal relationship. This paper makes a contribution in the intermediate field of stress relations. It presents the complete solutions of certain stress systems caused by various forms of boundary forces. Furthermore, the location and attitude of the fault surfaces likely to be associated with them is determined. For certain systems of external boundary forces acting on a portion of the Earth's crust, the internal stress distribution can be calculated by means of the familiar equations of elasticity. Appropriate calculation methods for two-dimensional cases are shown and the basic equations applicable to a series of important boundary conditions are derived. The examples here presented include: (1) superposed horizontal compression with constant lateral and vertical gradients, (2) horizontal compression with exponential attenuation, and (3) sinusoidal vertical and shearing forces acting on the bottom of a block. The latter equations provide solutions for differential vertical uplift and for the important case of drag exerted on the bottom of the crust by convection currents in the substratum. The resulting stress systems are illustrated by diagrams showing the configuration of the stress trajectories and the distribution of the maximum shearing stress. A second parallel series of diagrams shows the disposition between the relatively stable and unstable segments of the blocks and the probable attitude of the fault surfaces likely to be associated with the individual stress systems. The construction of the fault surfaces is based on the original stress distributions alone, the influence of local stress alterations due to the occurrence of fracture being disregarded. The full effect of this interaction is not known, due to the extreme complexity of the problem. The

fault patterns shown are strictly applicable only to the initial stages of fracture but may also represent fair approximations during the more advanced stages in view of the facts that the original stress remains the dominating influence and that stress-alterations due to faulting diminish rapidly with distance.

(4) H. W. Fairbairn (Massachusetts Institute of Technology, Cambridge 39, Mass.) Pressure shadows and relative movement in a shear zone--The determination of direction-sense of movement by means of pressure shadow orientation has been investigated by Mügge in some detail. As far as the writer knows, no correlation of this deduced direction-sense with a field example of relative movement has previously been made. Study of an oriented specimen taken from the Campbell shear zone at Yellowknife (N. W. T., Canada), where the direction-sense of movement has been established with reasonable certainty, now provides this correlation. Interpretation of the pressure shadow orientation around pyrite grains in the rock confirms the field data in every way. It would seem that this structure warrants closer attention and application than it has received heretofore.

(5) J. C. Maxwell and Gabriel Dengo (Princeton University, Princeton, N. J.) The Carupano area and its relation to the tectonics of northeastern Venezuela--The Venezuelan Coast Range in the vicinity of Carupano is lithologically and tectonically similar to the mountainous belt of low grade metamorphic rocks lying south of Caracas. Phyllites and slightly metamorphosed limestones in both areas show evidence of southward thrusting and overfolding. Along the coast north of Caracas and on the island of Margarita the metamorphic rocks have been thrust and overturned to the north. Apparently the Venezuelan Coast Ranges are part of a two-sided orogen with a northeasterly trending axis which passes south of Caracas and between Margarita and the mainland. Faults which are post-metamorphism in age cut both metamorphic rocks and Cretaceous sedimentary rocks. West of El Pilar a system of northwesterly striking faults localizes hot springs and sulphur deposits; one such fault separates the Cretaceous sedimentary rocks from metamorphic rocks. Available evidence indicates the Cretaceous sediments are not composed of detritus eroded from the low grade metamorphics of the Coast Range. Furthermore these sediments are nowhere known to be in sedimentary contact with the Coast Range rocks. In the Carupano area, at least, it seems probable that the phyllites and limestones of the Coast Range have been thrust and overfolded southward onto the Cretaceous sediments.

(6) S. S. West (Geophysical Institute, University of Alaska, College, Alaska) Tectonics of Alaska and adjacent regions--Stream directions and shorelines in Alaska, Siberia, and Canada show the existence of three major sets of almost perpendicular pairs of shear fractures, which correspond to forces originating (1) in the Beaufort Sea, (2) in the bay of the Arctic Ocean near latitude 70°N, longitude 123°E, and (3) in a direction a few degrees east of north from Bering Strait. Geologic evidence dates these fracture-sets, respectively, as having been produced (1) between Lower and Upper Cretaceous, (2) between Upper Triassic and Jurassic, and (3) in the late Carboniferous or earlier. The first and last sets correspond to the shear nets calculated by Vening Meinesz for shifts of the pole. Each of the three sets is associated with a distinct segment of the Aleutian island arc, whose dimensions are here compared with those predicted by the overthrust-theory of Gunn.

(7) H. E. Tatel (Department of Terrestrial Magnetism, CIW, 5241 Broad Branch Road, N. W., Washington 15, D. C.) Further considerations of Moon formation through resonance--H. Jeffreys has shown that friction is so great in a fluid Earth that an equilibrium tide of only 1/23 of the radius may be set up. This is insufficient to have caused the resonance disruption of the Earth to form the Moon. However, if the dissipation of energy is calculated under these conditions of an equilibrium tide, it is found to be very large - so large, in fact, that it could be enough to be cataclysmic. Under these conditions the friction might be diminished so that the deformation could then proceed to the point of bifurcation with Moon formation.

(8) Clifton W. Livingston (Colorado School of Mines, Golden, Colo.) An outline of research in subjects related to the mechanics of rock failure--The paper discusses the necessity of fundamental and applied research related to the mechanics of rock failure. Following a brief review of early and recent investigation of rock pressure problems, the results of current field and laboratory research pursued by graduate students in Mining Engineering at the Colorado School of Mines are described. The present and future research program is directed towards (1) the determination of the depth of cover necessary to provide protection against explosive blasts of high order, (2) the design of linings and supports for underground openings subject to bomb-burst, (3) the control and prevention of rock-bursts, (4) the mechanics of vein formation, (5) the control of local and regional subsidence in underground and open-pit mines, and (6) the improvement of existing mining methods through applications of fundamental principles of rock failure.

(9) D. S. Hughes and H. J. Jones (University of Texas, Austin, Texas) Variation of elastic moduli of sedimentary rocks with pressure and temperature--From a study of the transmission of dilatational pulses through rods it has been found possible to calculate not only the dilatational velocity but also the rotational velocity. From these velocities the elastic moduli of isotropic materials can be computed. The results are insensitive to boundary conditions and hence the method can

be used when the material is surrounded by oil in a pressure chamber. Various igneous and sedimentary rocks have been studied in the ranges 0-1100 kg/cm^2 and 25-175°C. The dilatational and rotational velocities and the elastic moduli as a function of pressure and temperature are presented for selected samples. A comparison of our results with those obtained by other methods is given. Although our measurements are based on pulses which have an equivalent frequency of 2.0-6.0 megacycles, there is no apparent discrepancy with low frequency and static measurements. This would indicate that, at least for the rocks for which a comparison can be made, dispersion is not important.

(10) Hatten S. Yoder, Jr. (Geophysical Laboratory, CIW, 2801 Upton St., N. W., Washington, D. C.) Change of high-low quartz inversion up to 10,000 bars--The change of the high-low quartz inversion temperature with pressure has been measured up to 10,000 bars. The relation of this change to Earth structure problems is discussed. Apparatus which has a working range up to 1400°C and 10,000 bars is described.

(11) John W. Handin and David T. Griggs (Institute of Geophysics, University of California, Los Angeles, Calif.) Predicted fabric changes in artificially deformed marble--The work of Griggs, Knopf, and Balsley provides three lines of evidence that gliding is the most important mechanism operating in the artificial dry deformation of Yule marble at high confining pressure. (1) The direction of change in the fabric of c-axes is that to be expected if intergranular twin or translation gliding occurs. (2) The strength of the marble is very different in three mutually perpendicular directions, and the marble is weakest when the stress is applied in a direction which is most favorable for twinning. (3) Single crystals deform by twinning when they are so oriented with respect to the stress axes that twinning is possible. Our purpose is to begin with hypotheses of the deformation mechanisms made likely be previous experimental work and analytically to derive deformation fabrics on the basis of these hypotheses. The predicted fabrics can then be compared to the actual observed fabrics to be reported on by F. J. Turner and C. S. Ch'ih. The geometry of the gliding processes is discussed. Equations are given for determining the resolved shear stress on glide planes, for calculating the amount of deformation due to shear, and for finding the amount of intragranular rotation of glide planes resulting from the shearing process. Deformation fabrics are derived on the assumption that deformation occurs entirely as a result of mechanical twinning on $(01\bar{1}2)$. Diagrams are presented for progressive amounts of tension and compression. It is found that the predicted changes agree qualitatively with observed experimental changes. It appears that twinning alone cannot account for the large deformations produced for certain orientations of the marble. More fabrics are then predicted on the assumption that deformation occurs as a result of translation on $(01\bar{1}2)$. It does not appear that translation alone can account for the great fabric changes actually observed. A third set of predicted diagrams is derived by combining twinning and translation, assuming that twinning and translation are each responsible for half the deformation. These fabrics most nearly resemble observed fabrics.

(12) Francis J. Turner and C. S. Ch'ih (University of California, Berkeley, Calif.) Observed fabric changes in artificially deformed marble--Petrofabric analysis of Yule marble artificially deformed by tension under high confining pressures shows significant change in preferred orientation of the space lattice of component calcite grains. Deformation lamellae parallel to $[01\bar{1}2]$ become increasingly conspicuous as deformation proceeds. There is evidence suggesting that these visible lamellae are due to twinning rahter than to translation. Nevertheless, reorienting of considerable parts of individual grains by twinning can be demonstrated only when the marble specimen has been strongly deformed (elongation of the order of 20 per cent). Reorienting of the space lattice of grains in slightly deformed marble is presumably due to some other mechanism - probably rotation of grains.

(13) William Schriever (University of Oklahoma, Norman, Okla.) On the origin of the Carolina Bays--A critical reconsideration of all important theories concerning the origin of the Carolina Bays led to a modification of the meteorite theory, and to the conclusions: (1) that Johnson's "theory of complex origin" is quite untenable; (2) that a meteorite theory of origin can meet all of Johnson's 29 requirements; (3) that a meteorite theory of origin has not yet been shown to be untenable; and (4) that a meteorite theory of origin is the least unsatisfactory of all the theories which havbe been published thus far.

(14) John W. Harrington (Southern Methodist University, Dallas, Texas) The elementary theory of subsurface structural contouring-- A system of analyzing subsurface data is developed through the use of a new method of graphical division and based on the recognition of special cases where more than three adjacent points lie on the same geometrical plane or nearly planar surface. These surfaces are then used to control the strikes of preliminary contours. The planes are also used in conjunction with cross sections to establish correction data for the placement of final contours. The uses of the system in drawing a new map and in evaluating an existing map are demonstrated.